Instruments

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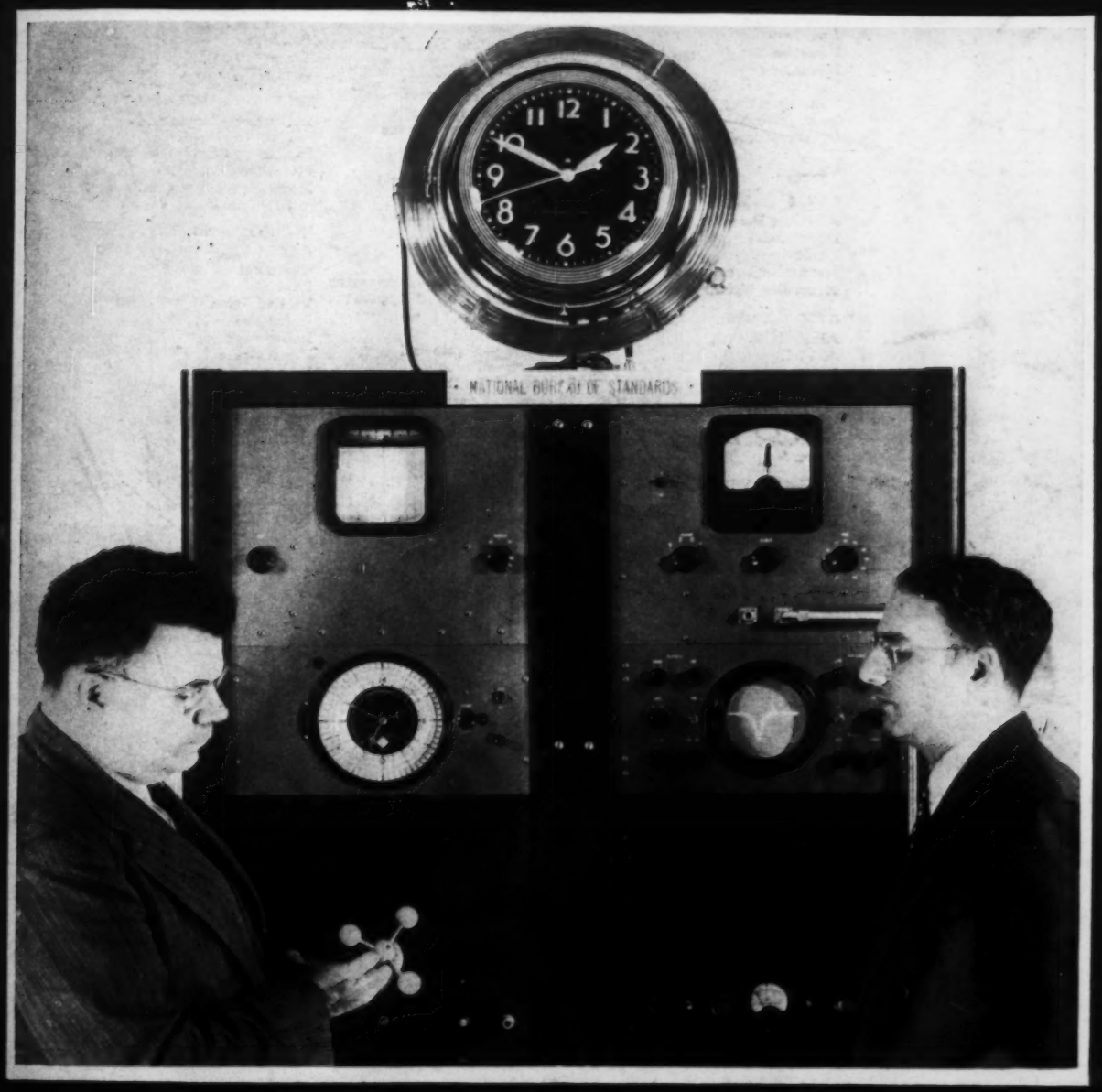

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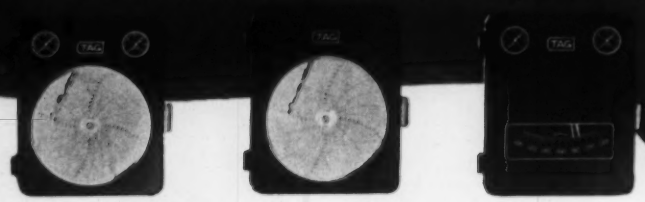

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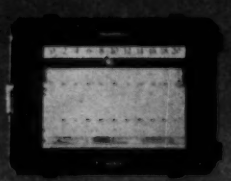

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591 Frelinghuysen Avenue, Newark 5, N. J.

TAG

EDITORIAL By M. F. BEHAR

Instrumentation's Foe: Statism

SOME call it communism; some call it fascism. Of course, communism and fascism differ in the way they germinate and grow; but in the end they add up to the same harsh rule of the many by the few—called by still other names, some of them scholarly terms such as authoritarianism and absolutism and totalitarianism; others simple and as old as human society: tyranny and oppression and slavery.

What's the idea of this kind of an editorial in this magazine? What's that got to do with meters and gages and control systems?

It has a lot to do with your job, your pay, your chances of design, develop, make, sell, buy, install, adjust, maintain, repair and service every kind of instrumentation product. It has a lot to do with your job, your pay, your chances of advancement, your pursuit of happiness in your chosen career—as well as with your political and economic liberty.

Why bring it up now?

Because right here in our America—in our national capital—before a joint session of the House and Senate—a number of socialistic measures including the construction and operation of new steel-producing facilites by the government—were proposed by the public servant holding the highest elective office within the gift of the people—by the President of the United States.

And because the protests died down in a few days, with comments such as: "Aw, he don't mean it; He's a safe guy at heart! Anyway, he ain't allowed to write those messages himself. A fella on the radio said Harry listens to the pressure groups and that means Big Business as well as Big Unions and the farmers! Yeah, and a Washington newsletter I subscribe to explains that he always takes an equal number of paragraphs from the conservatives and radicals around him so's to stay in the middle of the road! Sure, I know!"

Instruments does not pretend to know more than smart radio commentators and even smarter writers of high-subscription-price confidential business newsletters.

Instruments HOPES that this country will not drift into Statism: that the trend is only a swing of the pendulum.

Instruments, however, SEES signs that this drift is gathering momentum. We hasten to add that we do not refer to politics: the fact that at this moment in America's history one party is in and the other party out—this fact means only the acceleration of the drift; and a Republican administration would not have meant a pendulum-like reversal of this drift. No, perhaps not even a halt of this drift! And we can prove it by the utterances of the most influential Republican. We'll not quote last autumn's campaign speeches; we'll quote a Republican rally speech made in late January by Senator Robert A. Taft as summarized for the Scripps-Howard newspapers by Lyle C. Wilson:

Mr. Taft called the roll of the things he opposed: Price control, wage control, allocation control, socialized medicine, taxation at present high levels, universal military training.

Mr. Taft sought to bring the party up to date . . . by proposing:

1. An increase in the minimum wage.

2. Federal aid to states to extend medical care to all those unable to pay for it.

3. Federal aid to enable communities to provide housing for those unable to pay for decent homes.

4. Federal aid, especially to the poorer states, to assure primary and secondary schooling for all children.

5. Extension of old age pension protection to all persons not now covered.

There you have it!

Again, however, *Instruments* hastens to declare that it heartily approves the humane AIMS, sought for by Senator Taft and by his counterparts in the top leadership of the Democratic party. Every right-minded citizen wants to lessen poverty, disease, ignorance, slums, crime and other evils. One trouble with the popular thinking of this post-war world is the weary falling back on the false philosophy that the end justifies the means, when history has proved a hundred times—and is proving today in dictator-ridden countries—that the means determine the end.

The means determine the end. Never forget that for a moment, if you wish to preserve your economic and political freedoms!

What we instrument people have today—what all American citizens have today—as a result of the inspired genius of the Founding Fathers plus a century and three-quarters of a gradual process of refinement and modernization, is a precious heritage. It is a Federal Republic; it is Controlled Capitalism; it is freedom of speech, of assembly, of religion and of the press; it is recognition of the fact that human beings, not being angels, desire private possessions; it is Private Profit under safeguards that make it contribute to the Public Good.

It isn't Utopia; it's far from perfect; nevertheless it's the best system on earth today!

Government ownership of means of production, transportation, communications, etc.—government ownership of the steel industry—and consequently of the automobile, shipbuilding and other steel fabricating industries—government ownership of tools, yes, "instruments" (as distinguished from rivers and harbors, forests, uranium and other Divine gifts to all dwellers upon this land) would transform the American system into its opposite, namely Statism. The American *form* of government, with the secret ballot and other privileges, might remain, but the American system would vanish from technological fields. We technically-trained people, engineers, mechanics, etc., would all be government employees. And the farmers would come next, followed by (or preceded by) physicians, surgeons, dentists and nurses. Good-bye Incentive!

Stated bluntly, as in the preceding paragraph, the danger seems remote. We agree with the man-in-the-street that the President, in his own friendly Missouri farm-boy's heart, "ain't hankering for to have Uncle Sam make steel in competition agin the folks that make steel now."

Scientific developments unforeseeable by the Founding Fathers have complicated the situation even more by making it necessary for the central government to engage in a new metallurgical industry, to monopolize it and to guard the secrecy of its know-how: it is horrible to think that U-235, plutonium, and other fissionable materials could be made and owned by private citizens. The "atomic-energy industry" must therefore remain a U. S. government industry until it is turned over to an international authority—a Commission with the powers proposed in the U. S. Plan and opposed by Russia and her stooges. The U. S. Atomic Energy Commission, under Chairman Lilienthal, is doing its best to let out as many contracts as possible to America's private industries; but the laws of physics prevent complying with the full turn-over suggested by some Wall Street publications: atomic energy is isotopes for cancer research and a thousand other purposes; it is electric light and power; it is "a key to knowledge" as Lilienthal put it; but it is at the same time the Absolute Weapon.

Many other central-government functions unforeseeable by the Founding Fathers are highly beneficial—some of them directly beneficial to private industry as, for example, the multifarious activities of the National Bureau of Standards, many of whose projects were suggested by various industries and some of whose projects are supported in part by fees cheerfully paid by industrial firms.

In this complex modern age there are increasingly large areas for central-government functions—functions that protect and strengthen our democratic form of government. But if citizenry is not vigilant, centralization tends to expand to other areas where it does not belong—where it weakens our system and may destroy it.

Government ownership of a manufacturing industry inhibits Incentive and thereby hampers progress. If the steel industry had been federalized early in this century when "trust-busting" began, we would not have the mile-a-minute mills and other marvels made possible by automatic-control instrumentation; and our many steel-using industries, deprived of modern special alloys, would not be leading the world.

Methods *of* MINIMIZING ERRORS *in the* Measurement *of* High Temperatures *in* GASES

By E. MARSTON MOFFATT, Chief Engineer, Airflo Instrument Co., Glastonbury, Conn.

FOR a century the problem of measuring "the temperature" of a flowing gas stream has challenged man's ingenuity. More papers dealing with it have been presented before societies—and more articles in periodicals—than on any other temperature-measurement problem. Since it interests most of our readers, we have given it space in recent years; and we intended to print a list of selected references (a complete list would contain many articles giving false information and wrong advice). But such a bibliography is almost superfluous, for a bright young engineer (he is under thirty) fought and licked this problem during the war while working with . . . sorry, but he tells us that secrecy has not yet been lifted (as if it were a secret that the U. S. has many types of ram-jets, turbo-jets, rockets, gas turbines, etc.!).

This is the most informative article ever published on this subject; the most enlightening (or "de-bunking"); the most practical; the easiest to read; by far the best! We dare make these assertions because of tough experiences in our private consulting-engineering practice; by the same token we can predict that this article will make history because common errors of hundreds of degrees need no longer be tolerated. Its high proportion of original matter makes this article an important disclosure to be abstracted by publishers serving scientific and industrial circles: all drawings except parts of Figs. 1 and 2 are new; some equations are new; so is the method of determining the convective heat-transfer coefficient; so is the summing up of ALL errors; so are many specific discussions. —M. F. Behar, *Editor*

AT first thought, gas temperature measurements seem to be in a class with other physical measurements such as pressure and voltage: "everybody knows" that errors are present and "almost everybody" assumes that they are accounted for. But temperature measurement, besides being one of the most useful measurements, is also the most difficult to make because there is no true thermal insulator which even approaches the standards of electrical or pressure insulation. In conducting a pressure from one point to another, a pressure-tight tube can be used and no one would even consider trying to calculate possible errors due to leakage through the tube walls. In other words the tube is a perfect pressure insulator.

Now then, if a pressure tube were made of cheesecloth and led through a region of varying pressure and an attempt were made to calculate the pressure at one end from the pressure indicated at the other, the problem would be as complex as gas temperature measurement. There is only one pressure acting at a point in a gas stream; but there are a great many different temperatures acting at the same point: the gas temperature itself, and all the temperatures of the walls of the gas passages within sight of the point by radiation. The calculations of all these radiated temperatures and their effects are similar in nature and complexity to optical calculations because heat radiation is simply light at a different wave-length.

A temperature probe for hot gas can be a mercury thermometer, a resistance bulb, a mercury-in-steel bulb, a gas or vapor bulb, or a thermocouple. The probe itself is placed in the gas passage and its temperature is assumed to be equal to the temperature of the gas. The temperature of the probe, or rather of its primary element, is indicated by various means. In a mercury-in-glass thermometer the primary element and indicator are combined—a temperature rise at the bulb makes the mercury expand and the expansion is measured by graduations on the stem. With a resistance thermometer the indicator is a resistance bridge connected to the primary-element resistor by lead wires. With a thermocouple a potentiometer is used to measure the voltage generated in the thermocouple circuit, which depends on the difference in temperature between the primary-element junction and the reference junction. With a vapor-pressure, mercury or gas pressure-spring thermometer, a temperature rise at the bulb causes a pressure rise which, through a connecting tube, deflects a pressure gage calibrated in degrees of temperature.

WHY THERMOCOUPLES?

In each of these types of temperature probes the indicator is supposed to show the temperature of the primary element, and they all have to be calibrated against some other standard. Each one has advantages for certain applications and certain temperature ranges. For high temperatures, mercury-in-glass thermometers are obviously impractical (although a special type using a high-temperature glass and mercury under pressure has been used as high as 1000 F.). The resistance type is delicate and difficult to build in a satisfactory form because of the requirement for supporting and insulating a large amount of fine wire in a small space. The mercury-in-steel and vapor bulbs are limited in temperature range. The gas bulb has errors due to the porosity and change in volume of the bulb at high temperatures and errors due to temperature variations along the connecting tube.

The thermocouple can also have large errors, mainly due to changes in calibration of the wire with use. Against this, it has the advantage of small size (a very important property as shown later) and a simple rugged construction which is easily insulated; so it is preferable to any other type of thermometer for most high-temperature uses. The errors due to change in calibration of the wire with use can be reduced by proper handling and installation, by protecting the wires, and by choosing the proper thermocouple alloys for use at the different temperatures. With calibrated wires and the proper potentiometer and connecting circuit, a thermocouple can measure temperatures to within two degrees in the range 1000-2000 F.—or an accuracy of roughly 1 part in 1000 on an absolute temperature scale. An uncalibrated industrial thermocouple probably reads within 20 degrees in this range.

This particular error, which is the difference between the actual temperature of the primary element and the temperature shown by the indicator, is probably less for a thermocouple than for any other type of thermometer at high temperatures. But this particular error is a circuit error or an instrument error, i.e., a *secondary* error and, even if it were zero, the probe could still be off 500 degrees or more because the primary element is not necessarily (in fact never) at the same temperature as the gas. The rest of this article discusses the causes and magnitude of this *primary* error at high temperatures—*the temperature difference between the gas and the primary element*—and the secondary or instrument errors discussed above are assumed to be zero. (This assumption can be approached in practice by calibrating every thermometer against a known standard—a procedure which unfortunately cannot be applied to eliminating the primary error.) The secondary error depends only on certain properties of the temperature-measuring system—all the way from probe to dial or chart; but the primary error depends on the method of use of the probe.

The primary errors are due to:

1. Heat radiation from the probe to (and to the probe from) walls and solid objects at different temperatures;
2. Heat radiation from the probe to (and to the probe from) the gases at different temperatures;
3. Heat radiation from luminous flames to the probe;
4. Heat conduction along the wires and supports of the probe;
5. Velocity errors which make the gas temperature at the probe something different from its static temperature.

Primary errors would affect any type of thermometer equally, whether a mercury-in-glass, resistance element, mercury-in-steel, gas or vapor bulb, or thermocouple, as long as the primary element was of the same size and shape and had the same conductivity and emissivity. Since the errors are reduced for a small sized element (as shown later) and since the thermocouple can be made smaller than any other type, the thermocouple will have smaller primary errors as well as smaller secondary errors at high temperatures.

In order to see these errors in their proper perspective, a brief discussion of certain common assumptions and misconceptions is helpful:

In the first place "error" is not quite the correct term for these effects (though we intend to keep on using it). The use of the word implies that the probe should measure the gas temperature when it is placed in a gas stream; and the fact that it doesn't measure the temperature is regarded as some fault in the probe rather than in the basic assumption. This is comparable to assuming that a sailboat moves at the same speed as the wind; the wind speed certainly affects it but so do numerous other factors such as tides, currents, hull design, direction, waves, and any auxiliary power it may be using. A sailboat is obviously a poor wind-speed indicator and in a parallel vein a probe is basically a poor gas-temperature indicator. A habit of thought carried over from calibrating thermometers against a standard to eliminate secondary errors has led to many fruitless attempts to calibrate high-temperature probes against some single variable—this variable is usually absolute temperature and since this is only one of the important ones the results have not had any widespread use.

It is pertinent at this point to bring out two facts: (1) A probe, besides being inherently inaccurate, messes up the gas flow by obstructing the passage. (2) There are other possibilities for measuring gas temperature directly without inserting any object in the gas stream. One method uses the sodium line reversal technique to measure the temperature without radiation, conduction, and velocity errors by spectrographic means through a window. Another method would measure the temperature acoustically since the velocity of sound in gas depends only on its temperature. Both of these methods suffer from other types of errors, the chief one being caused by temperature variations in the gas itself.

Which brings up the second point, namely, the definition of the gas temperature: There is no such thing as a single gas temperature throughout a given cross-section, because the temperature is never uniform when it is high, being maximal in the center of a duct and approaching a minimum equal to the wall temperature at the edges. If an average is desired, the type of average must be decided on and calculated from point measurements of temperatures, pressures and velocities. The ability to measure point temperatures (however inaccurately) is one of the outstanding advantages of the probe, the others being its simple installation in remote locations and simple construction and operation.

The common fallacy of expecting a probe to respond to gas temperatures—and to gas temperatures alone—probably stems from the use of air thermometers at room temperatures. Under ordinary conditions the air and the room are at the same temperature, so it is a matter of indifference whether the thermometer is actually measuring the temperature of the air or of the walls, floor and ceiling. But it is recognized that as far as comfort is concerned the air temperature in a room does not determine the "effective" temperature. This is the basis of radiant heating—a floor temperature of, say, 75 F. will make a room feel comfortably warm even though the air temperature may be 50 F. or lower. In this case a human body responds to the environment temperature as would the primary element of a thermometer. The floor heats it more by radiation than the air cools it by convection. A mercury-in-glass thermometer with the bulb blackened to make it absorb radiant heat like a human body (with clothes on, of course) would probably indicate a temperature of around 65 F. If the bulb were made as large as the body it would indicate around 70 F., or if a conventional mercury-in-glass thermometer with clear glass were used it would read closer to the air temperature—say 55 F. The definition of "room temperature" in a case like this obviously is impossible: there is no room temperature in the sense of a single undisputed measurement. If a strong draft were to blow through the room with the same temperatures, an observer would feel colder in spite of the radiant floor heat. The higher the air velocity, the more nearly the effective room temperature would approach the air temperature. These effects are all paralleled at high temperatures; but the effects of radiation are enormously greater because the amount of radiation from a surface increases as the fourth power of the absolute temperature—it is 245 times as much as 1600 F. as at 60 F.

As a brief aid to analysis it should be noted that the following characteristics of a probe will make it read closer to the gas temperature than to the wall temperature:

1. Small size;
2. Low emissivity—which means a highly reflective surface like a mirror;
3. High gas velocity—related to the probe rather than to the gas stream because the velocity past the thermocouple can be changed independently of the stream velocity by appropriate design of the probe.

If the walls and gas are at the same temperature (as aproached in a small heat-treating furnace) there are no large primary errors in measurement. All the errors arise with gas flowing past walls at a different temperature and in such a case the temperature indicated by the probe will usually lie somewhere between the gas and wall temperatures.

The most important test conditions which will make a probe read closer to the gas temperature are:

1. Walls of the test rig at practically the same temperature as the gas;
2. High pressures;
3. Low temperatures.

Usually nothing can be done to change the second and third factors, but a test rig can often be designed to reduce the error due to the first factor.

In ordinary home heating it is commonly observed that the apparent temperature of a room with considerable window space is higher when the air is humid than when it is dry. Under these conditions a body can lose heat by radiation through the windows to, say, a snowbank. Humid air is less transparent to heat radiation than dry air. Hence it acts as an insulator against radiation. At high temperatures this effect is chiefly noted in gases containing water vapor and carbon dioxide (which are present in considerable quantities in a hot gas produced by burning hydrocarbons such as fuel oil). The effect is proportional to the concentration of these gases and usually acts to reduce the radiation error of the probe. As an example, a probe used in a gas stream produced by burning three different fuel-air ratios had less than half the error at the high ratio than at the low because of the greater percent of water vapor and carbon dioxide in the gas.

Gases Radiate and Absorb

The concept of gas radiation is a little confusing at first because the gas both radiates and absorbs heat by radiation and at the same time transmits a large amount of radiation through it just as though it were not present. As an approximation (which is approached when the probe, gas and walls are at practically the same temperature) the gas will absorb a certain percentage of the radiation from both the walls and the probe and radiate the same amount back. The remainders of the radiations from the walls and probe will affect each other directly. Under ordinary conditions (when the gas is hotter than the probe and the probe is hotter than the walls) the gas will radiate a certain amount of heat to the probe, thus tending to raise its temperature the same way as gas convection does; and at the same time it will absorb a certain amount of the radiation from the probe which otherwise would be radiated to the walls and thereby cut down the heat transfer from the probe to the walls. This second effect—usually the more important—permits the gas to be considered as an insulating blanket which reduces the error of the probe. The insulating effectiveness of the gas depends on the concentration of molecules of carbon dioxide and water vapor and also the "path length" for radiation. In other words it depends on the

total number of molecules of the absorbing gas which the probe can "see" in all directions.

This raises the question of what value can be assumed for an average gas temperature, since obviously all of the gas which the probe "sees" is not at the same temperature. Analysis of the process shows that the gas nearest the probe is the most effective in this radiation; so, as a simplifying assumption, the effective temperature of the gas for radiation is usually taken as the gas temperature *at the probe*. Since this is the value which is to be measured in any case, this is very convenient; however, errors could occur in measurements taken in regions of high temperature gradients (such as occur near the walls of a test rig) where the gas radiation would increase the error of the probe.

Another commonplace effect is the sensation of heat thrown out by an open fire. This heat is due to direct radiation from the luminous flames (which contain particles of white-hot soot) and not to the heating of the air. The amount of radiation is almost equal to that from a white-hot iron bar the size of the flame. Since flames are usually hotter than any solid parts of a test rig, and since their total radiation increases as the fourth power of the absolute temperature, they are responsible for large errors in high-temperature probes. Nearly all the errors in probes are due to walls cooler than the gas which tend to lower the indicated temperature. However, luminous flames have the opposite tendency and might make the probe read higher than the gas. It is practically impossible to predict the amount or even the direction of the error when a probe is exposed simultaneously to a luminous flame and hot gas at lower temperatures with cool walls. The use of probes under such conditions has resulted in rather astonishing data, including some showing indicated burner efficiencies of 110 percent!

Gas-Stream Velocity Errors

A final source of error which has no parallel in ordinary experience but is mentioned now as a hazard with supersonic aircraft is due to very high gas velocities. It was mentioned before that a high velocity is an advantage in reducing radiation errors, but there can be too much of any good thing and eventually a point is reached where velocity errors are greater than radiation. The velocity error is due to the air being compressed when it strikes a stationary object, such as a probe. This compression produces a temperature rise, as if the gas were compressed by a piston. The temperature which would be measured by a thermometer moving at the same speed as the gas is known as the Static Temperature. This determines the density and other physical properties of the gas and corresponds to atmospheric temperature for a high-speed airplane. The static temperature is parallel to static pressure. The maximum temperature which the gas tends to reach when it is stagnated is the "stagnation" or Total Temperature—parallel to total pressure. The difference between these two (the adiabatic temperature rise) depends only on the specific heat of the gas and the velocity.

For air this temperature rise is proportional to the square of the velocity. Its value in degrees Fahrenheit can be computed easily: by squaring the velocity in feet per second and dividing by 12,000. (This purely verbal statement is instantly recognizable as an equation. There will be others; therefore it may be—and is—numbered as Equation No. 1.) The velocity error is directly proportional to the adiabatic temperature rise.

The Effective Gas Temperature at the probe is something between the total and static temperatures. It depends mainly on the shape and orientation of the probe and to a lesser extent on the velocity, pressure, and temperature. It is calculated from the Recovery Factor thus:

Effective Temperature equals (static temperature) plus Recovery Factor, times (total minus static temperature). (Eq. 2)

The recovery factor varies from 0.65 to 0.90 for unshielded thermocouples. For specially-designed total-temperature probes it is as high as 0.99. The total temperature is much easier to measure than the static—no probes have ever shown a recovery factor much below 0.65. For efficiency calculations in airflow the total temperature is more convenient to use than the static because it eliminates the effect of velocity. (We won't venture an opinion on which is the "true" gas temperature until somebody decides whether total or static pressure is the "true" gas pressure.)

In the jet of a jet engine at 1500 F. the gas velocity is 2200 fps. and, with a cylindrical probe having a recovery factor of 0.80, the velocity error is 80 F. based on total temperature, or 325 F. based on static temperature. Actually the error would be lower if the recovery factor of the probe were known, because a correction factor could be applied. The recovery factor can only be found by accurate calibrations and, since it is impossible to make these calibrations even at low velocities and high temperatures, there would probably be at least 5 percent error in the recovery factor assumed, giving a corresponding temperature error of 20 F.

This velocity error is usually serious only above 400 fps. and is most serious in artificially-aspirated probes. These probes are designed to reduce radiation errors by sucking the hot gas at a high velocity past the thermocouple. Before velocity errors were heard of, these probes were assumed to measure accurate gas temperatures because by increasing the aspirating suction the indicated temperature would rise to a maximum and then level off. It was later shown that this maximum is reached when the decreasing radiation error is just equal to the increasing velocity error; and that it will always be lower than the true gas temperature. Since it is practically impossible to measure the recovery factor and velocity in an aspirated probe there is no way of calculating its error in actual work with such a probe.

Additional Errors

Before discussing these primary errors further, some additional errors and their approximate magnitude in the gas temperature range of 1000 to 2000 F. should be mentioned. These errors are all important when attempts are made to calculate temperature errors *theoretically*. Theoretical corrections are based on generalized theories and properties of matter, which in turn are derived from actual experiments, so their accuracy is no better than that of the original experiments. Sometimes this practical basis is lost sight of (a failure especially noted among mathematicians engaged in engineering) and the corrections are assumed to be as infallible as the laws of nature. It is a sobering thought, however, that one of these accepted laws, namely the impossibility of perpetual motion, is based on the experimental fact that no one has ever succeeded in building a perpetual motion machine. (Even the Patent Office has recognized that this is impossible.) High-temperature probe errors involve dealing with most of the basic concepts of physics such as electromagnetic energy radiation, the quantum theory, and the kinetic theory of gases, so there is a wealth of scientific data to draw on, but the actual calculations in numbers are based on properties of matter at high temperatures—a field of experimental physics which

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For MATHEMATICAL READERS, *the most important equations, in the usual symbols*

$$q_c = q_r \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$q_c = h_c A (T_g - T_p) \quad Btu/hr \quad . \quad (4)$$

$$q_r = \sigma \epsilon A \left(\frac{1+F_1}{2}\right)(T_1^4 - \overline{T}_w^4) \quad Btu/hr \quad (5)$$

$$q_r = h_r A (T_p - \overline{T}_w) \quad Btu/hr \quad . \quad (6)$$

$$h_r = 4 \sigma \epsilon F_1 \left(\frac{T_p + \overline{T}_w}{2}\right)^3 \quad . \quad . \quad . \quad (7)$$

$$Error \quad T_g - T_p = \frac{h_r (T_g - \overline{T}_w}{h_r + h_c} \quad . \quad . \quad . \quad (8)$$

$$Percent\ error \quad \frac{T_g - T_p}{T_g - \overline{T}_w} = 100 \frac{h_r}{h_r + h_c}$$

$$= \frac{100}{1 + (h_c/h_r)} \quad . \quad (9)$$

A *area, ft²*

F_1, F_2, F_3 *geometrical factors for radiation*

h_c *convective heat transfer coefficient; &*

h_r *radiative do., both in Btu/hr·ft²·°F.*

T *temperature, °F. or as specified*

T_g *effective gas temperature*

T_p *temperature indicated by probe*

T_w *wall temperature*

$\overline{T}_w$ *average wall temperature for radiation*

ϵ *emittance (radiant, total)*

σ *first radiation constant (or Stefan-Boltzmann constant) = 1.73×10^{-9} when English units are used in $q = \sigma A T^4_{abs}$ Btu/hr*

Instruments Pittsburgh

is practically untouched. The extent of experimental data available at present in this field is summed up in what follows.

Sugar-coated Sugary Math —Easy to Take and Use

First of all, a simplified heat balance: Considering only (1) radiation errors due to radiation between solids and (2) heat transfer by convection from the gas to the probe, the probe temperature is stabilized when the heat input by convection is equal to the heat output by radiation:

Convective Heat IN equals Radiated Heat OUT. (Eq. 3)

This equation is an abridged form of one to be given later (Eq. 10), in which additional variables will be included.

The convective heat input (in Btu. per hour) is the product of the convective heat transfer coefficient, times the surface area of probe (in square feet), times the difference between the effective gas temperature and the probe temperature (both in deg. F.). (Eq. 4)

The radiated heat out (also in Btu. per hour) is the product of the Stefan-Boltzmann constant for radiation (expressed in English units), times the emittance of the probe surface, times a geometrical factor, times the surface area of the probe (in square feet), times the difference between the fourth power of the Average Wall Temperature for Radiation and the probe temperature (both absolute: deg. F. plus 460.) (Eq. 5)

It is more convenient to put this relation into a form similar to the convective heat transfer. Thus the radiated heat is the product of the radiative heat transfer coefficient, times area, times difference between the probe temperature and average wall temperature. (Eq. 6)

In this case the radiative heat transfer coefficient can be computed (with only a negligible error for most applications) as follows:

Four times the Stefan-Boltzmann constant, times emittance, times a geometrical factor, times the cube of the average of the probe temperature and average wall temperature. (Eq. 7)

Note.—The dependence of this coefficient on the cube of the average absolute temperature (instead of the fourth power) is merely a matter of convenience in calculations. Use it where you can assume that you have a fairly constant temperature difference and a varying absolute temperature.

Combining these expressions enables us to find the error of the probe, in terms of the temperature difference between the gas and the walls, in an equally simple way: the ratio (radiative heat transfer coefficient times difference between gas temp. and average wall temp.) over (sum of radiative and convective heat transfer coefficients). (Eq. 8)

From this, by simply rearranging terms, we get the PERCENT ERROR, which is equal to 100 times the radiative ht-tr. coeff., over the sum of the radiative and convective ht-tr. coeffs. (Eq. 8)

The Percent Error can also be expressed as 100 over (one plus convective ht-tr. coeff. over radiative ht-tr. coeff.). (Eq. 9)

This expression shows that if the convective heat-transfer coefficient is extremely large compared to the radiative heat-transfer coefficient, the percent error approaches zero, i.e., the probe temperature equals the gas temperature. If the radiation is extremely high the error approaches 100 percent, i.e., the probe temperature equals the wall temperature.

This shows also that as long as the radiation is not zero and the difference between gas and wall temperatures is not zero (which they never are) and no other effects are present, *the probe temperature can never equal the gas temperature.*

The Convective Heat-transfer Coefficient

At this point we may go back to our heat balance; but instead of the simple one expressed in Eq. 3 we now consider three more variables which are sources of error in practice. These additional errors can be accounted for by adding them to the right-hand side of Eq. 3, thereby obtaining the more thorough expression:

Convective heat in equals radiated heat out, plus radiation to flames, plus radiation to hot gases, plus heat conducted along stem of probe. (Eq. 10)

These three additional terms will now be considered in consecutive order.

Radiation to flames equals Stefan-Boltzmann constant, times probe emittance, times flame emittance, times a geometrical factor, times the difference of the fourth powers of the absolute flame and probe temperatures. (Eq. 11)

Radiation to hot gases, likewise, equals Stefan-Boltzmann constant, times probe emittance, times gas emittance, times area, times difference of fourth powers of absolute gas and probe temperatures. (Eq. 12)

As for the heat conducted along the stem of the probe away from the primary element, it generally is small and its calculation is too complicated to consider in this article. It involves the conductivity of the solid parts of the probe and the calculation of equilibrium temperatures for every other part of the probe in a manner similar to Eq. 8 for the primary element.

In Eq. 10 some of the terms may balance each other so that the probe temperature will equal the gas temperature (since the terms may be either positive or negative) but this coincidence is just as unlikely as the insurance man's favorite accident: when four cars enter an intersection simultaneously.

One type of probe design—the heated shield and heated thermocouple probes which are discussed later—inject another term into the equation, namely the electrical heat input to the probe. This heat input is adjusted theoretically to compensate exactly for the other errors so that the probe temperature will equal the gas temperature. This is "an experiment noble in purpose," as was said of Prohibition—and a tricky one to consummate.

In all these equations the velocity error was neglected because it is taken into account in the Effective Gas Temperature. The velocity error can be calculated independently from Eqs. 1 and 2 to correct the Effective Gas Temperature to the static temperature or to the total temperature.

The convective heat transfer coefficient is one of the most difficult to evaluate. Errors as high as 100% are possible. This coefficient is of course a function of various flow phenomena and, therefore, is most conveniently defined in terms of the Nusselt Number and of the Reynolds Number. Also affecting this coefficient are the Prandtl Number and the Mach Number. All four of these numbers are dimensionless ratios of great usefulness in hydrodynamics and aerodynamics because each characterizes a certain type of flow. The best-known is the Reynolds Number: at Reynolds Numbers below about 2000 the flow is laminar or viscous; at Reynolds Numbers above about 2200 the flow is turbulent.

The Reynolds Number is made up of a length (such as the I.D. of a cylindrical pipe), times the velocity of the flowing fluid, times the density of the fluid (at the particular spot under study), over the absolute viscosity of the fluid. When these four values are expressed in consistent units the result is a pure number which exactly characterizes the average turbulence in a pipe or duct cross-section—or, in the alternate case, *outside* a solid body such as an airfoil moving in the atmosphere or a stationary probe in a gas stream.

The Nusselt Number, sometimes known as the boundary modulus, is equal to the convective heat-transfer coefficient, times a length (such as a diameter), over the thermal conductivity of the gas.

The Prandtl Number is equal to the specific heat (at constant pressure) times the absolute viscosity, over the conductivity. These are three properties of the gas, and its velocity is not involved directly.

The Mach Number is well-known as the speed of a projectile or aircraft, over the velocity of sound in air at the altitude under study. In gas temperature work, it is the velocity of the gas past the probe, over the velocity of sound in the gas but at the temperature existing during the test.

With so many variables affecting the convective heat-transfer coefficient, it is likely to change during a test. The determination of the important Reynolds and Nusselt Numbers is difficult, even in preliminary investigations under the most favorable laboratory conditions with a simple body such as a solid cylinder. For example, experimental results on a cylinder perpendic-

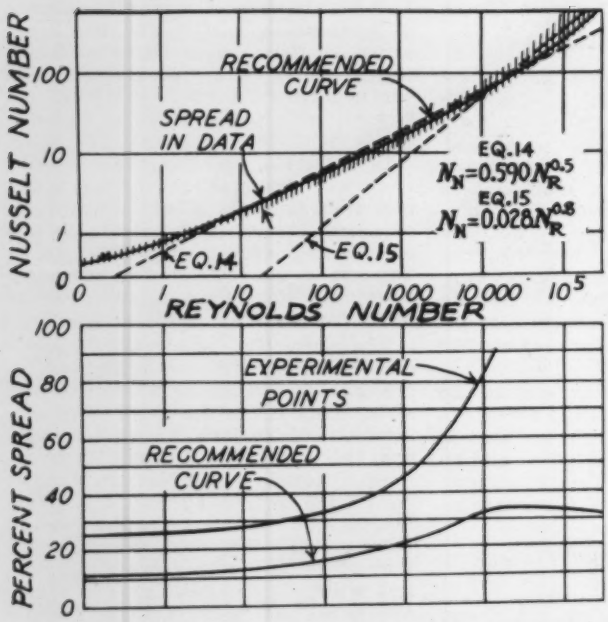


Fig. 1. Experimental curve (from McAdams' "Heat Transmission") of Reynolds Number versus Nusselt Number for cylinders perpendicular to flow. Dashed lines (present author's Eq. 14 and 15), same for flow over flat plates. Convective heat-transfer coefficient is found from these new curves, being equal to Nusselt Number multiplied by conductivity of gas and divided by diameter of cylinder or length of flat plate.

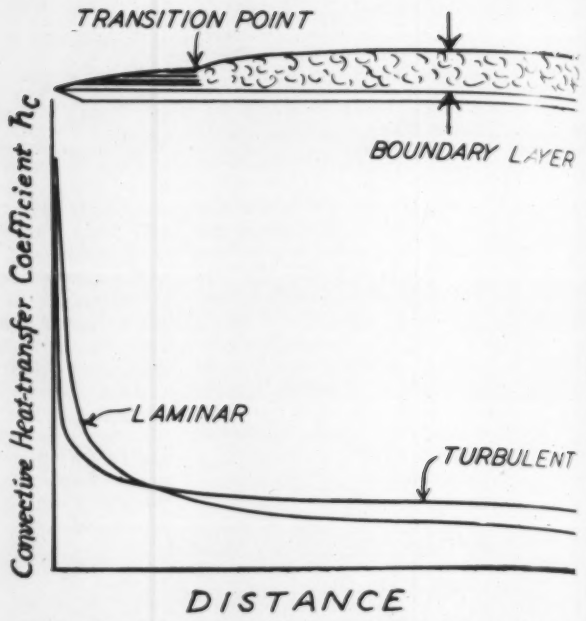


Fig. 2. Characteristic flow over any body, showing how an insulating boundary layer builds up from the leading edge. Lower curves show values of heat transfer coefficient at different distances from the leading edge. These are *local values*. In Fig. 1 the coefficient is the *average* over the length.

ular to flow are shown in Fig. 1 where the Nusselt Number is plotted against the Reynolds Number. The spread in these data, which was chiefly due to neglecting the other variables, is shown in percent on the lower curve. This shows a spread as high as 100 percent.

The basic flow process involved is shown in Fig. 2. When the gas flows over an object, such as a flat plate, a boundary layer is built up at the surface owing to friction. The flow in the first part of this layer is laminar, that is, there is no turbulence and the gas flows in streamlines parellel to the surface. The heat transfer from point to point in the gas outside this layer is very high because of turbulent eddies, so the whole gas stream outside the boundary layer can be considered to be at a uniform temperature—the Effective Gas Temperature. The heat flow through the layer to the plate, however, depends on the conductivity of the gas which is much lower than the "eddy conductivity" of the main stream, so there is a sharp temperature drop in this zone. This boundary layer may be likened to an insulating blanket of varying thickness.

The common expression for heat conduction through a solid states that the rate of heat conducted (in Btu. per hour) is directly proportional to the area and to the conductivity of the material, and inversely proportional to the thickness. Comparing this with Eq. 4 for the rate of convected heat, it can be seen that the convective heat-transfer coefficient is the conductivity over a "thickness"—in this case the thickness of the boundary layer. Aerodynamic experiments check heat transfer data very well in showing that this virtual thickness depends on the Reynolds Number with the "length" factor taken as the distance from the leading edge. The relation for the laminar boundary layer states that its thickness is equal to a constant times this distance from the leading edge, over the square root of the Reynolds Number.

If the surface is long enough, the flow in the boundary layer itself becomes turbulent so that its conductivity is increased but also its thickness. Strangely enough, the flow around a cylindrical body (and probably most streamlined bodies) is so similar that the same equations with the same constants apply as to a flat plate; thus the two equations (14 and 15) for laminar and turbulent boundary layers respectively, are the ones which appear in Fig. 1.

In these, the length is the projected length in the direction of flow (equals the cylinder diameter for a perpendicular cylinder). These two equations, which were derived both experimentally and theoretically for flat plates, are plotted as straight lines on the upper curve of Fig. 1, showing how well they fit the data for cylinders.

The actual value of the convective heat-transfer coefficient in Eq. 14 and 15 is an average over the flow length. The local values drop very rapidly from an infinite amount at the leading edge as shown in the lower curves of Fig. 2. Obviously, the average value decreases with the flow length—that is, with increasing size of the body. This explains the large effect of probe size on temperature errors. *A small probe will always read more accurately than a large probe of identical design under the same flow conditions.*

The chief error in using these equations to predict the convective heat-transfer coefficient is in picking the proper equation, i.e., for the laminar or turbulent boundary layer. The transition point depends on the initial turbulence of the air and the roughness of the surface and the results are less reliable for the turbulent than for the laminar boundary layer.

The flow conditions described above and applying to the probes are quite different from the conditions that determine the heat coefficient in a long pipe (the system most familiar to engineers dealing with heat transfer). In a long pipe these conditions prevail at the inlet but the boundary layer rapidly grows until it fills the whole pipe and it is then more appropriate to use a constant coefficient (which depends on Reynolds Number determined by the pipe diameter) and a varying gas temperature. Errors in dealing with long pipes are frequently due to neglecting these inlet conditions and, conversely, errors in probe calculations are frequently due to assuming that the heat transfer is similar to that in a long pipe. Very often the convective heat-transfer coefficient is thought of as a property of the gas—such as its density — and the same coefficient is assumed for the probe as for the walls of the pipe. This has even led to experimental programs aimed at developing a "coefficient meter" to be used in developing heat transfer apparatus.

The physical properties involved in all these heat-transfer equations are:

Gas conductivity;
Gas density;
Gas viscosity;
Specific heat of gas;
Surface emissivity;
Gas emissivity;
Flame emissivity;
Conductivity of solids;
Gas compositions.

In low-temperature work, atmospheric air is almost the universal medium and, except for changes in humidity, it has a fixed composition. At high temperatures there usually is a considerable amount of water vapor and carbon dioxide from the products of combustion. There may also be carbon monoxide and hydrogen from incomplete combustion, various sulphur compounds, and other gases.

It is conventional to assume atmospheric air for gas composition even at high temperatures except for gas radiation; errors introduced this way are noted below:

The Conductivity of a gas is very difficult to measure at any temperature. Errors for air alone at high temperatures may be 20 percent. No simple way is known of predicting the conductance of a mixture of gases from the conductivities of its components.

Density: The most accurately known. Can be calculated from the pressure and temperature for air or mixtures. (Less than 1 percent error).

Viscosity: In the same class as conductivity—errors up to 20 percent.

Specific heat at constant pressure: Quite accurate—can be calculated for mixtures, say 2 percent error.

Emissivity: The surface emittance can range from 1.0 for a perfect radiator (a blackbody) to zero for a perfect reflector. All bodies fall between these two limits. For most industrial surfaces the value is 0.8 at high temperatures with a probable error of 10 percent. Clean silver and gold have emissivities of about 0.03 at high temperatures but it has never been found practical to keep them clean in industrial atmospheres owing to sulphur, lead, and carbon deposits from the gas. These impurities also affect other materials, so the emittance of an actual surface depends to some extent on the gas composition. Since the radiation loss is directly proportional to emissivity, a low-emissivity material is ideal for simple probes. Calibrations of silver-covered probes have been satisfactory in clean atmospheres for short exposures. Since contaminated silver approaches an emissivity of 1.0, however, there is a possibility of a thirty-fold change in the error. This uncertainty is usually worse than a fixed large error. In this connection it should be noted that polished stainless steel will have an emissivity of about 0.2 at high temperatures and it usually takes several hours to become black. Occasionally, a too-literal interpretation is made of the terms "light" and "black." The properties of the body in the infrared are the important ones, not in the visible spectrum, so even though the properties are usually the same in both, a black-colored object does not necessarily have an emittance of 1.0; nor a light-colored object a low emittance.

Gas Emissivity: Very dependent on gas composition and may reach values as high as 0.2 or 0.4 for certain opaque gases. The error in calculating it probably averages around 20 percent or more.

Flame Emittance: Depends on the "soot concentration" and depth of flame. It approaches 1.0 for deep luminous flames and is almost impossible to calculate for any other case.

Probe Conductivity: There are probable errors of 20 percent in this conductivity, depending on the material. Since conduction errors are usually small, this is not too important.

Patience and Persistence Bring Rewards

It might seem hopeless to even attempt a calculation of temperature probe errors and, in the sense of calculating an exact quantity, it is hopeless. But the equations given in this article are useful for two reasons:

1. They make it possible to estimate the errors which will occur under various conditions—indicating how large a tolerance should be assigned to each measurement. This might be about five degrees for a heat-treating furnace and 500 degrees for measurements near a burner with cold walls.

2. They aid in designing probes to minimize the error and permit a calculation of the maximum error of such probes. Thus, even with errors of 50 percent in the calculations, it is an advantage to know that a shielded probe will read within 5 to 10 degrees of the true temperature as compared with a bare probe reading from 100 to 400 degrees off.

Neglecting the physical errors above, it is worth while to look into the problem of determining the test conditions which influence the probe. These are:

Velocity;
Temperature;
Pressure;
Flow direction;
Turbulence;
Wall temperature.

Velocity can be calculated from the measured temperature and measured total and static pressure. (These last two can usually be measured to an accuracy of 2 percent.)

The temperature and static pressure together determine the gas properties density, viscosity, conductivity, and specific heat, to be used in the preceding calculations.

Since the temperature is unknown and nevertheless must be known before the calculations can be made, the usual procedure is to assume the gas temperature equal to the probe temperature, calculate the difference and the actual temperature and then use this new temperature to re-calculate the error. This step-by-step solution will eventually result in the correct answer as far as the mathematics is concerned but the first calculation is usually close enough so that only one step of the procedure is carried out. (Strangely enough, most engineers who have started with the idea of getting temperatures accurate to 2 degrees are willing to settle for 10 or even 20 degrees after a few days of figuring.)

The flow direction is usually known except for elbows and behind curved guide vanes and can be measured even in these cases with auxiliary instruments.

The turbulence cannot be measured at high temperatures with present techniques and causes errors in convective heat-transfer coefficient.

The wall temperature can be measured theoretically by placing enough thermocouples on the walls of the test rig. This seemingly simple requirement can never be met in practice, however, because with the common variation of wall temperatures found it would take too many thermocouples. In one test rig it was found that even 24 thermocouples placed on the walls of the duct before and after the probe were insufficient to permit accurate wall temperatures to be calculated.

Importance of What the Probe "Sees"

To appreciate this problem from another angle, the question can be asked, "What color is a mirror?" Obviously, the color of the mirror is the color of the object it reflects. To two observers situated in different parts of a room, a mirror may be two different colors at the same time. Any solid surface with an emittance less than 1.0 acts as a mirror for radiation. An oxidized stainless steel surface with an emittance of 0.8 (which appears black to the eye) is still 20 percent efficient as a mirror for heat reflection. Only 80 percent of the heat it radiates is due to its own temperature and 20 percent is reflected from some other source. Strictly speaking, then, the probe radiates to all the surfaces within "sight" (in a direct line) *plus all the surfaces reflected to the probe*. From this welter of radiation at different temperatures the probe selects the Average Wall Temperature for Radiation. Fortunately, the probe can solve this problem in a few seconds where two mathematicians could work for a year without getting the right answer. To simplify this problem it usually is assumed that the wall surfaces surrounding the probe have an emittance of 1.0. In most cases the error in this assumption is not large. In one special case the assumption is perfect. This case exists only when all the walls are at the same temperature. Since the reflected radiation is at the same temperature as the emitted radiation, the walls act just as though they had an emissivity of 1.0 and we then have the "blackbody enclosure" of physics textbooks. But if the probe is situated around an elbow from a luminous flame in an attempt to shield it from direct radiation, the reflected radiation will cover a larger field of vision than the flame itself would and the resulting error may be even higher than if the probe were in direct view of the flame.

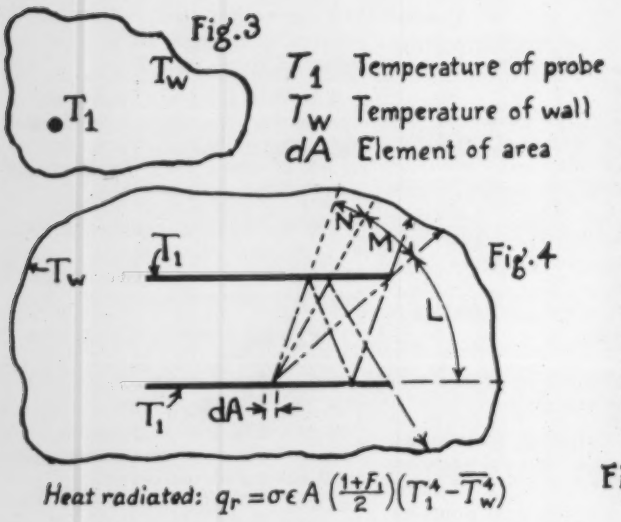


Fig. 3. The simplest case for radiation losses: a small body in an enclosure with walls at a uniform temperature.

Fig. 4. A more complicated case for radiation where the body partly "sees" itself by radiation as well as the walls. In this case the effective surface area of the body for radiation to the walls depends on both its shape and its emittance.

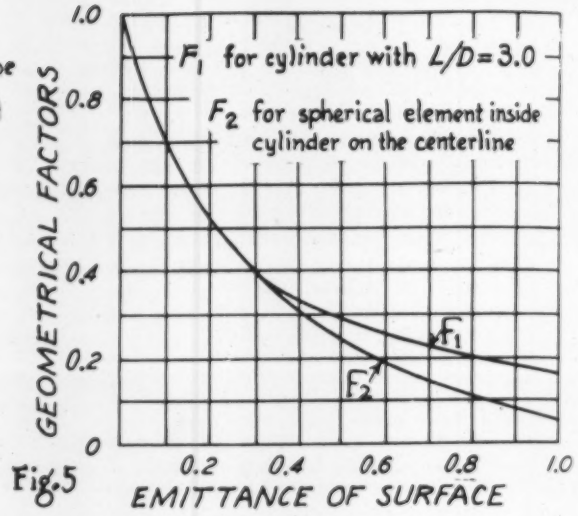


Fig. 5. Geometrical factors $F1$ and $F2$ for radiation for examples shown in Figs. 4 and 6.

Some Illustrative Examples with Quantitative Data

Assuming a wall emittance of 1.0, some typical examples can be shown:

Fig. 3 illustrates the simplest case. The probe at the probe temperature is surrounded by walls at a uniform temperature. For this case, the "Average Wall Temperature for Radiation" of Eq. 5 is the wall temperature; and the geometrical factor of Eq. 5 (in this case F_1) is 1.0.

Fig. 4 shows a wall at a uniform temperature but the probe surface in this case is a hollow cylinder like the shield on a shielded probe. Any part of this surface "sees" a different wall temperature because it can radiate directly to the wall through an angle L, radiate by one reflection from the opposite wall of the cylinder through an angle M, by two reflections through an angle N, etc., for an infinite number of reflections. The effective wall temperature for this case is taken care by $(1+F_1)/2$, where F_1 is the geometrical factor in Eq. 5. The values of this factor, for different emittances of the cylinder with an L/D ratio of 3.0, are given in Fig. 5.

Fig. 6 is for a thermocouple inside a cylinder. The effective wall temperature for the thermocouple is a combination of shield temperature and wall temperature. In this case the average wall temperature in Eq. 5 is given by the relation under the drawing in Fig. 6; and the geometrical factor F_2 is given for different emissivities in Fig. 5.

The calculation of the two curves in Fig. 5 took about a week of mathematical work; their line-width accuracy should be an incentive to their users to determine emittances of surfaces as accurately as possible.

Fig. 7 is for a bare thermocouple in a duct with varying wall temperature. The temperature of the duct walls is assumed constant at any cross-section and only varies along the axis. This approximates many cases met in practice. In this case as in any practical case the *shape* of the thermocouple element affects the radiation. The element radiates more in a direction perpendicular to its surface than in any other, so only a sphere radiates equally in all directions. Any other shape can see better in some directions than others, like a horse with blinders. For this case, the average wall temperature in Eq. 5 is calculated from the relation under the drawing of Fig. 7. This value is obtained graphically by multiplying the value of the geometrical factor F_3 (Fig. 8) at each angle (M) by the fourth power of the wall temperature, plotting the result against the angle M and measuring the area under the curve with a planimeter.

In Fig. 8 the value of F_3 at each angle is proportional to the amount of radiation from the probe to the duct at that angle. Curves are shown for four different shapes—a sphere, cylinder, and flat plate both parallel and perpendicular to flow. Comparing the perpendicular cylinder with the parallel plate (curves 2 and 3): The cylinder radiates 11 percent of its heat to the

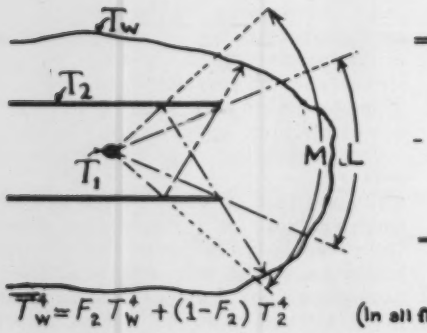


Fig. 6. A typical case for radiation losses, where a body at temperature $T1$ radiates directly to a wall and surface at temperature $T2$ and also by reflection to the wall and surface.

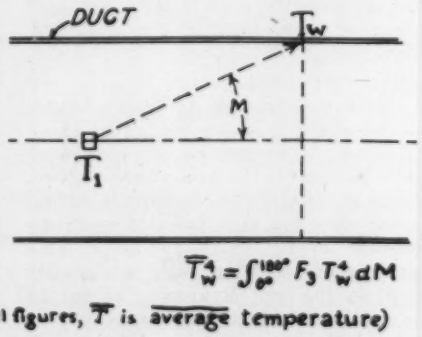


Fig. 7. Radiation from a probe at temperature T1 to a duct with wall temperatures varying along its length. Average wall temperature for radiation is given by the equation above and F3 for different shaped elements is shown in Fig. 8.

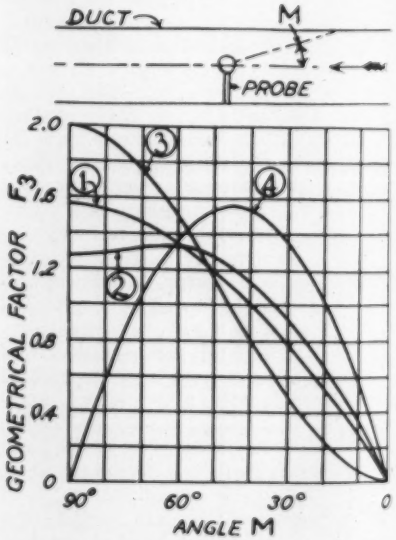


Fig. 8. Curves to be used with Fig. 7.
Curve 1: A spherical element.
Curve 2: A cylinder perpendicular to axis of duct.
Curve 3: A plate parallel to axis of duct.
Curve 4: A plate perpendicular to axis of duct.

duct walls which are more than one diameter upstream and downstream from its position (angle M being less than 90 and more than 26 degrees) and the parallel plate radiates only 3 percent to those "end zones"; thus, measuring the wall temperatures in this region allows a fairly accurate calculation of average temperature to be made, particularly for the parallel plate. This property is utilized in the concentric-shield probes to make them relatively insensitive and "end radiation" — out the open ends of the shields.

Some other typical examples of average wall temperature are shown in Figs. 9 and 10. These bring out the error caused by the common assumption that the effective wall temperature for radiation is equal to the temperature of the walls nearest the probe.

Fig. 9 is for a probe in a duct with a linear wall temperature gradient ranging from 540 to 1160 F. as shown. The error is only 5 degrees in this case.

Fig. 10 is for a probe behind a turbine disk at a temperature of 940 F. with wall temperatures from 540 to 740 F. The error is 55 degrees.

Fig. 11 is for a bare probe in a burner rig exposed simultaneously to radiation from the flame at 3000F., gas at 900 to 1100 F., duct walls at nearest-the-probe temperatures ranging from 600 to 1000 F. around the periphery (at right angle to the plane of the paper), and a cold exit zone at 90 F. The effective wall temperature for radiation is plotted for each position along the duct for two differently-shaped probes, (the original one and one described below), for a perpendicular cylinder, and for a parallel plate. Comparing these with the local wall temperatures at each point (which most workers ordinarily use for calculating radiation instead of using the effective wall temperature for radiation), the advantage of the parallel plate can be seen. The curve of the average wall temperature for the plate is within 100 degrees of the wall temperature for the probe at all points and averages within 40 degrees; whereas the curve of the average wall temperature for the cylinder is as much as 200 degrees away from the wall temperature for the probe and averages 175 degrees off.

To show the effect of this discrepancy on the calculated error, the indicated temperature of a cylindrical probe a quarter-inch in diameter (with an emittance of 0.8 with a gas at 200 fps. and atmospheric pressure) is shown on the curve below as a band of "MEASURED" temperature. It is impossible to draw a single line for this, because with an actual rig under the assumed conditions the measured temperature would also depend on variables like turbulence, gas emissivity, and probe emittance—all of which could vary considerably not only from day to day but with variations in operating conditions. The measured temperatures would range from 20 degrees above to 69 degrees below the true gas temperature, depending on the probe position.

"CORRECTED" temperatures are shown as another band in the lower part of Fig. 11. These are the temperatures that would be obtained by standard methods of correction outlined in heat transfer books. They are shown by Eq. 8 and assume the effective wall temperature for radiation equal to the wall temperature for the probe. The "corrected" temperatures range from 70 degrees above to 40 degrees below the true gas temperature, so in this case they would be more in error than the uncorrected values. They would give an over-optimistic measurement of burner efficiency and indicate a greater temperature drop in the gas as it flows away from the flame than would actually be the case.

If these results were used as a basis for re-designing the burner they might lead to the conclusion that the burner efficiency was satisfactory and that the heat loss in the duct was excessive, so valuable time might be spent on adding insulation to the duct instead of concentrating on improving the burner efficiency.

This is a typical example of the cost of inadequate instrumentation in a development program. Other examples could be quoted since high-temperature measurements are also important in measuring turbine efficiency and in many other applications.

Fig. 12 shows an example of another type of error. This is the conduction error, which is usually small as long as the probe is small and has sufficient "immersion" in the gas stream. In this example the thermocouple is encased in a quarter-inch stainless steel tube and placed inside a shield assembly. The temperature of the inner shell of the shields is considerably higher than the walls, so if the thermocouple assembly were made of a perfect thermal insulator the temperature along its length would follow the dotted lines T_{e1} and T_{e2}. Since the primary element is at the tip it would be at a temperature T_{e1} and the error

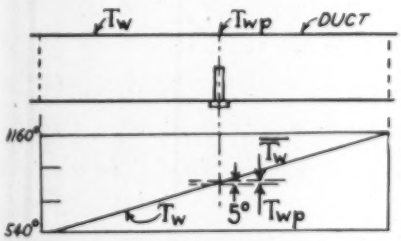


Fig. 9. Simple illustration of the error in making a radiation correction in a pipe with uniform wall temperature gradient when Twp, the wall temperature nearest the probe, is used in Equation 5 instead of the average wall temperature.

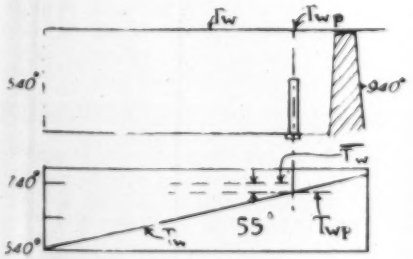


Fig. 10. Another example of the error (this time in a turbine rig) in using the nearest-wall temperature Twp instead of Average Tw.

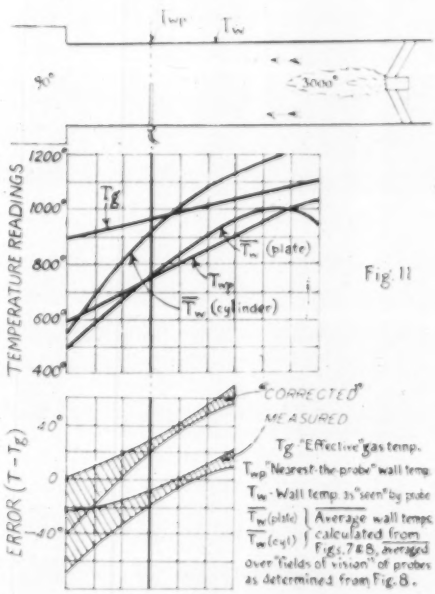


Fig. 11. The center curves show variation of gas temperature, Tg, and wall temperature, Twp, in a burner rig downstream from a burner. Ave. Tw (plate) and Ave. Tw (cylinder) are calculated from Figs. 7 and 8 for each position for probe elements shaped respectively as a plate parallel to flow and cylinder perpendicular to flow. (These Ave. Tw values are average over the whole "field of vision" of the probe as determined from Fig. 8.) The lower set of curves shows "measured" temperatures as the actual error of a cylindrical probe under the conditions shown in the curves above. This error depends on Tg and Ave. Tw (cylinder). The "corrected" temperatures curves show the error resulting from correcting the data by conventional methods using Tg and Twp.

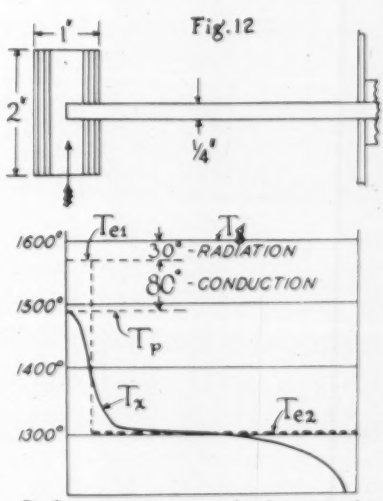


Fig. 12. Illustrating conduction error in a shielded probe. Radiation error (Tg-Tel) is less than the conduction error (Tel-Tp) for this case.

which is due primarily to radiation would be T_g-T_{e1} or 30 degrees. In the actual case heat can flow along the element and will tend to equalize the temperatures so the temperature distribution will follow the curve T_x and the temperature at the tip will be 80 degrees lower owing to conduction. This is an unusual case where the conduction error is larger than the radiation but the example is taken from a commercial probe and the assumed test conditions are air at 1600 F., walls at 1200 F. and 50-fps. velocity at atmospheric pressure. The error in this case could be reduced by using a smaller element and immersing it deeper in the inner passage.

All these examples except the last were for bare probes. It was shown before that the source of the primary error is the temperature difference between the gas and walls of a rig; hence the best way to minimize the error is to bring these two temperatures closer together. This can be done by enclosing the thermocouple in a chamber whose wall temperature is higher than that of the test rig and which allows a free flow for the gas. A single cylindrical shell will usually cut the error in half. The temperature of the shield can be calculated from Eq. 8, when the shield itself is considered the element. Then using this shield temperature and taking into account the end radiation out the open ends, an average wall temperature for the element can be calculated and the element error found from Eq. 8.

Fig. 13 shows the results of some calculations on a single-shielded probe with a gas velocity of 200 fps. at atmospheric pressure, when the emittance of either the shield or element varies.

These curves show some rather astonishing results.

Curve 1 shows the error for a bare element—its error decreases to zero as the emittance decreases to zero. Curve 2 for an element and shield of the same emittance shows approximately half the error of the bare element. Curve 4 shows that if the element emittance is 1.0 *the error actually increases as the shield emittance approaches zero.* This seems to contradict the general impression that a low-emissivity material in a probe will always result in lower radiation errors. However a study of the system and comparison with Fig. 6 shows the reason: As the shield emittance decreases, the shield becomes a more efficient mirror and the element is actually "seeing" the walls and responding to their temperature to an increasing extent as the reflectance of the shield increases. In the limiting case where the shield emittance is zero, its temperature has no effect whatever on the thermocouple since it simply acts as a mirror for wall radiation. The element temperature in this case will be the same as for a bare probe.

Curves 5, 6 and 7 show the same results for a heated-shield probe. This type of probe, which is considered in more detail later, aims at eliminating the radiation error by measuring the shield temperature with a thermocouple and adjusting it with an electric heating coil so that it always equals the thermocouple temperature.

Curve 6 for this type, with a shield of perfect emittance (1.00) and an element of varying emittance shows the lowest error of any type. The error in this case is all due to direct radiation out the open ends of the shield. Considering a practical construction for a

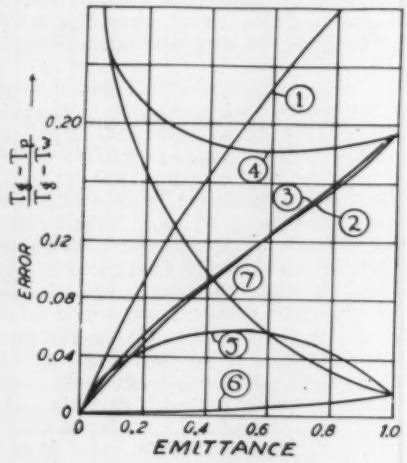


Fig. 13. Radiation errors of a single shielded probe. (Cylindrical shield with *L/D* ratio of 3). Showing effects of low emittance materials.
Curve 1: Bare probe.
Curve 2: Element and shield with same emittance.
Curve 3: Shield emittance 1.0; element varying.
Curve 4: Shield emittance varying; element 1.0.
Curve 5: Heated shield: Element and shield emittance the same.
Curve 6: Heated shield: Shield emittance 1.0; element emittance varying.
Curve 7: Heated shield: Shield emittance varying, element 1.0.

moment, where both element and shield have the same high emittance, Curve 5 shows that the error with an emittance of 0.8 is 4.5 percent as compared with an error of 2 percent for an emittance of 1.0 and the maximum error of 6 percent is reached with an emittance of 0.5. In this case it would actually pay to blacken the probes to reduce the radiation error. Curve 7 for an element emittance of 1.0 and a varying shield emittance shows the largest change of error of any—a variation of about 15 to 1. With a shield emittance of zero the complicated heated-shield probe is no better than a bare thermocouple.

Considerable emphasis has been placed on these curves because a large amount of time and effort has been spent on building and calibrating heated-shield probes with and without low-emittance components and such probes have been advocated as standards for calibrating other probes. Silver is generally used and its emissivity is assumed to be about 0.03 at high temperature. The curves all show that if the actual emittance can be kept this low all the designs will have the same error (about one percent) because the curves 1, 2, 3, 4, and 5 converge at this point, so a simple silver-covered element is as good as any other design. However, if the heated shield is used and the element accidentally becomes blackened the error will increase roughly by a factor of 15. (Curve 7). There are so many other unpredictable variations in the errors of probes that it would seem good practice to eliminate this particular error.

Multiple shielded probes can be built to compound the shielding of the single shield. It is a fairly well-known fact that radiation shields in a vacuum (or approximately in a stagnant gas) will

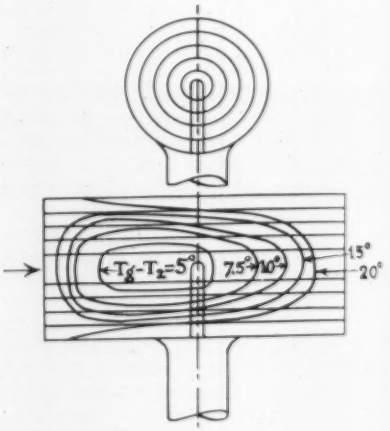


Fig. 14. Calculated temperature distribution in degrees below the gas temperature T_g in a five-shielded probe for gas velocity and temperature of 400 fps. and 1600 F. and wall temperature of 1200 deg.

reduce the heat loss of a heated body to cool walls by a factor of roughly the reciprocal of $n+1$ where n is the number of shields. With gas flow through the shields, the compounding is even more effective, so the error is reduced by a factor of approximately the reciprocal of a constant to the nth power; where the constant depends on design and operating conditions and is usually equal to 2 or more. If a value of 2 is assumed, with four shields, the error is reduced to the reciprocal of 2 to the fourth power, or one-sixteenth of its value for an unshielded element. The actual errors of multiple-shielded probes are much more complicated than this, but this gives an idea of their possibilities. By increasing the value of the design constant and the number of shields, the error can be reduced to any amount desired. The problem then in applying this probe to a particular test is to decide on an allowable error under the worst conditions and use a probe which has the necessary accuracy without any correction factor.

Fig. 14 shows the calculated temperature distribution in a 5-shielded probe under the same test conditions as Fig. 13. (Wall temperature 1200 F.). The temperature distribution will not be symmetrical with respect to the center line of the probe because the local convective heat-transfer coefficient will be higher at the entrance than at the exit.

The calculation of this single graph represents desultory mathematical work over a period of several years and concentrated work for about two weeks; and the graph is offered only as an approximation. The calculations involved, among other things, the computation of the gas velocity inside the shields as compared with the free-stream velocity and the effective wall temperatures for each of the shields at each point along their length by a procedure similar to that shown in Fig. 4 but with the added complication that it is not possible to consider the shields independently, calculate the outer shield temperature,

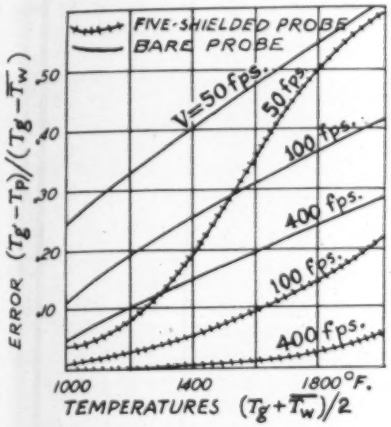


Fig. 15. Comparison of calculated errors with a bare probe (0.030" thermocouple) and a five-shielded probe, for various temperature levels and various gas velocities.

then each of the inner ones in succession to get the result, because the temperatures of all points of all the shields must be calculated simultaneously. This is necessary because of the large, approximately equal areas of the shields and their influence on one another. (In the simpler examples considered before it is adequate to assume that the single shield temperature is determined only by the walls and gas and not by the thermocouple.)

Fig. 15 shows other calculations for a 5-shielded probe compared with a bare probe at atmospheric pressure but varying velocity and absolute temperature. The shielded probe is proportionately better at the higher velocities giving practically zero error at 400 fps. up to 1400 F. At 50 fps. and high temperatures it approaches the error of the bare probe because of the greatly reduced velocity through the shields and the decrease in the convective heat-transfer coefficient. It is not sufficient to assume for these probes that the velocity through the shields is equal to the free-stream velocity or even proportional.

Fig. 16 shows some calculations with a single-shielded probe which is aspirated, at 1600 F. and atmospheric pressure, with varying gas velocity past the thermocouple, assuming a recovery factor of 0.65. This shows that the velocity error based on the temperature of the slowly moving gas stream outside the probe is equal to the radiation error at 800 fps., and the minimum over-all error of 35 degrees is reached at a velocity of 600 fps.

These aspirated probes are useful in low-velocity streams and can be built in multiple-shielded designs to have characteristics similar to Fig. 15. If the free-stream velocity is excessive, as in the jet of a jet engine, the velocity and the error can be reduced easily

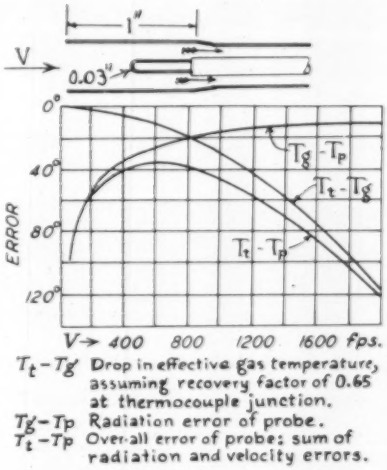


Fig. 16. A typical aspirated probe with aspirating velocity V in fps. Tt-Tg is the drop in effective temperature of the gas assuming a recovery factor of .65 at the thermocouple. Tg-Tp is the radiation error of the probe, Tt-Tp is the overall error of the probe—the sum of the radiation and velocity errors.

with a shielded probe by restricting the flow through the shields with a perforated disk or other dam.

Fig. 17 shows a typical heated-shield design with a heater coil and auxiliary thermocouple at a controlled temperature surrounding the thermocouple at "probe temperature." If there were no end radiation and the heat were adjusted to equalize these two temperatures, there would be no radiation error. Actual errors can occur for four reasons:

1. The impossibility of measuring the temperature difference exactly. This difference is measured by comparing the readings of two thermocouples at high temperatures where contamination is important and the calibration changes with use. It is doubtful if this can be measured any closer than about a couple of degrees. In fact, discrepancies of this extent have been found between heating and cooling cycles of two thermocouples whose junctions were welded together.

2. Temperature variations in the shield. This will make the average shield temperature different from the shield-couple temperature—say another two-degree discrepancy.

3. End radiation out the open ends of the shield.

4. Heating and cooling of the gas passing over the heated shield which makes it temperature something different from the free stream temperature.

A typical case for this probe was calculated at a gas temperature of 1600 F. and a wall temperature of 1200 F., with 50-fps. gas velocity at atmospheric pressure. The results showed that the error (difference between gas temperature and probe temperature) is equal to a constant times the difference between the probe temperature and the *average* shield temperature (which is the sum of errors 1 and 2 above, or about four degrees). The value of the constant depends on design and test conditions and is determined by the

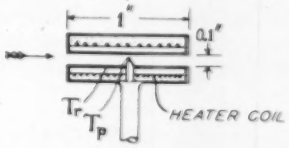


Fig. 17. A typical "heated shield" probe with a heater coil surrounding the inner flow passage, the temperature of the inner wall measured by a thermocouple Tr and the gas temperature measured by a thermocouple Tp. (Illustration is two-thirds actual size.)

size of errors 3 and 4 above. In this case, its value was 4, so the error of this fairly conservative design of heated-shield probe is 16 F. under the assumed conditions.

A better design might have a lower error but, unless it were much better than a multiple-shielded probe, it would not be worth the trouble of building and using this type. The form of the error equation shows the weakness of this design. The difference between the probe temperature and the average shield temperature is the irreducible minimum of control error and unless the design-and-test constant is less than unity, this difference is the minimal error. The constant usually is an amplifying factor which increases the error. The probe in this case acts as an error amplifier because the added electrical heat can force the probe temperature above its equilibrium value determined by operating conditions alone. To reduce this constant, errors 3 and 4 would both have to be reduced together —and here's the rub: To cut down the end radiation, the flow passage inside the probe would have to be lengthened or curved: but this automatically increases the temperature change in the gas from the free stream to the element, thereby increasing error 4. Increasing the gas velocity by aspirating the probe or increasing the size and length would help reduce 3 and 4 but the probe would probably be too bulky then for any practical use, beside being expensive to build and operate. At least, the error would probably be no less than for a compounded-shielded aspirated probe. This is like using a trailer truck to deliver a package of birdseed and then getting stuck in the driveway.

Aspirated probes, incidentally, although indispensable for some cases, introduce an amazing amount of extraneous labor and maintenance. Blocking of the aspirated lines solid with carbon, burning the operators, and dis-

posing of the hot gas are only a few of the troubles.

Fig. 18 shows the last example. This is a heated design but the thermocouple junction itself is heated to balance radiation losses. The balance point is indicated by aspirating the gas over the junction cyclically, i.e., with a pulsating flow. This type is insensitive to end radiation. If the shield temperature remained constant it would work. With a constant heat input to the thermocouple the temperature will fluctuate as the gas flow fluctuates past the thermocouple if it is at a different temperature from the gas. However, when it is just equal to the gas, the temperature fluctuations will cease because at that point there is no heat transfer from the thermocouple to the gas and the electric heat input is just sufficient to overcome the radiation loss to the shield and surroundings. The temperature is then read at this zero fluctuation point. This design is very attractive in its simplicity and in avoiding most of the errors of the heated-shield type. But it would not work if the shield temperature fluctuated too. (There are other errors but this is the major one.) It is difficult to see any way of avoiding this fluctuation because the shield will be heated cyclically by the gas and even if it is very massive there will be fluctuations in its inner surface temperature, which is all that matters. Analysis shows that the thermocouple temperature fluctuations might be brought to zero by applying the right heat but this balance would be reached when the variations in the shield temperature were in phase and just sufficient to offset the variations in the convective heat-transfer coefficient at the thermocouple. A typical error for this design at a temperature of 1600 degrees and atmospheric pressure was calculated and showed an error of 35 degrees F. *higher than the gas temperature.*

Conclusions

To sum up the results reported in this article the following points should be emphasized:

1. Radiation errors depend on the temperature difference between the gas and the walls of a rig—this general definition of walls including luminous flames. Other conditions tending to increase the error are high absolute temperatures, very high and low velocities, and low pressures.

2. Errors in calculated correction factors can often be so high as to make them valueless.

3. The best experimental technique is to use probes with the accuracy for the job and use their readings without any correction.

To some readers it may seem that the errors in gas temperature measurements are over-emphasized in this article—especially those readers who remember the many technical papers published in recent years showing methods of correction without spotlighting the pitfalls. On the other hand, these same figures may seem too conservative to readers who have used various methods and various types of probes. In point of fact, the foregoing quantitative data, drawings and discussions are some of the results of several years' intensive experience, testing most of the types of probes described, attempting to build accurate probes and to calibrate them —as well as a perusal of all the available literature. The sequence of development was to start with multiple-shield probes and bare probes, try some fancy varieties, and return to the multiple-shield type as the best bet.

The problem has received attention from most large scientific institutions and many large manufacturers; and

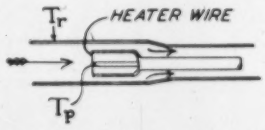


Fig. 18. A "heated thermocouple" probe showing the aspirating passage for varying the flow velocity and the thermocouple *Tp* heated electrically.

their published results have been very valuable. No one however has attacked the problem on the basis of a sustained experimental program; it has always been a side-line to some other development. No single institution is in a position to solve the problem or willing to accept the cost of a development which would benefit all the industries using high-temperature gas measurements and the published results have often given the impression that there is no serious problem or that the problem has been solved.

The difficulty of solving the problem theoretically has been indicated by this article. But the difficulties with an experimental test rig to actually calibrate probes under all operating conditions are even greater. In most cases calibration programs of this type have been limited by the design of the rig (and underestimating the difficulties). The ultimate solution would be to design a rig from the basis of theoretical considerations and experience with all other types that have been tried and conduct an experimental program simultaneously with theoretical work. This type of program would also answer a number of other questions regarding the physical properties of matter at high temperatures—which in turn would be of direct benefit to the industries.

The author has had the mortifying experience of engaging in such a program and finding such contradictions as a large probe reading closer to the true temperature than a small one under the same conditions (the emittance of the large one was lower) and a 7-shielded probe read lower than a 5-shielded one (reason unexplained). It all led to the conclusion that no single temperature reading can be depended on. Only by taking a large number with independent probes and making check runs can the miscellaneous and consistent errors be eliminated and the problem reduced to the form shown in this article: use as many probes as possible and don't believe any single reading of any single probe.

It might also be questioned how investigators in industry have made such progress in work dealing with hot gases if the errors are actually this large. The answer is simple: they have used substitutes for gas temperatures. They recognize that bare probes don't show the gas temperature but they only use them for duplicating operating conditions and are not interested in the actual temperatures. In many industries the operating conditions of a piece of apparatus are set by the allowable temperatures of the materials used in construction, so a probe which measures some sort of average of the gas and all the wall temperatures is useful. In most development programs, accurate probes could have greatly simplified the problem. In the field of gas turbine development accurate gas temperatures are the most useful. A complete engine could be designed, developed, and tested, without using a single gas temperature measurement but this procedure is reminiscent of a squad of blind men with machine guns hunting deer in competition with a sharpshooter with a rifle.

The economical procedure is to develop the engine components—compressor, burner, and turbine — separately and then combine them. Gas temperature measurements between the stages of a turbine make it possible to calculate the efficiency of each stage independently. They measure burner efficiency and they track down "hot spots" which burn the walls.

It is interesting to note that the following variables are determined by gas temperature alone (for engineering accuracy):

Viscosity;
Conductivity;
Specific heat;
Total energy input and output;
Carnot efficiency.

The temperature is one of the indispensable variables which determine:

Density;
Gas radiation;
Convective heat transfer (which determines the temperature of the walls of a rig);
Massflow rate;
Velocity.

The only important measurements in gas turbines that don't require gas temperature measurement are:

Mechanical power output and thrust;
Metal temperatures and stresses;
Fuel consumption.

(A complete power plant *could* be developed with these measurements alone).

Until some good substitute for gas temperature is invented, the temperature probe is here to stay—along with its family of errors.

THE ATOMIC CLOCK

By HAROLD LYONS, Chief, Microwave Standards Section, National Bureau of Standards, Washington, 25, D.C.

A BASICALLY NEW primary standard of frequency and time, invariant with age, has been developed at the National Bureau of Standards. The new standard takes the form of an atomic clock based on a constant natural frequency associated with the vibration of the atoms in the ammonia molecule. This, the first atomic clock ever built, promises to surpass by one or two orders of magnitude the accuracy of the present primary standard, the rotating earth. It is controlled by a constant frequency derived from a microwave absorption line of ammonia gas, providing a time constancy of one part in ten million. Theoretical considerations indicate a potential accuracy of one part in a billion or even ten billion, depending on the type of atomic system and spectrum line used.

The present crowding of the radiofrequency spectrum has imposed severe limitations, both nationally and internationally, on the expanding use of radio for industry and communications. The atomic clock may be expected to benefit greatly the communications industries and the military services, for it will, in effect, provide additional room in the radiofrequency range for more communication stations of all types. The present "radio space" allows for a drifting of each station's frequency, so that a broad "radio space" is required to avoid interference with other stations. Utilization of available "space" thus depends on the accuracy with which individual station frequencies can be controlled, especially at the higher frequencies used by radar, television relays, and microwave equipment in general. These frequencies, where quartz crystals cannot be used as frequency-controlling elements, could be controlled by atomic elements. Such control would also make possible the permanent establishment of radio channels on such an exact basis that tuning could be made as automatic as the dialing of a telephone number.

The improvements in frequency and time measurement offered by the atomic clock are also of fundamental importance in many fields of science. An absolute time standard will be of special importance in astronomy, where present time standards leave much to be desired.

The atomic clock and the new invariant method represent important tools of research and development in every technical field where precise measurements of time and frequency are crucial—for example, in long-range radio navigation systems, in the upper range of the microwave region where atomic systems can serve as electronic components, in microwave spectroscopy, and in research in molecular structure.

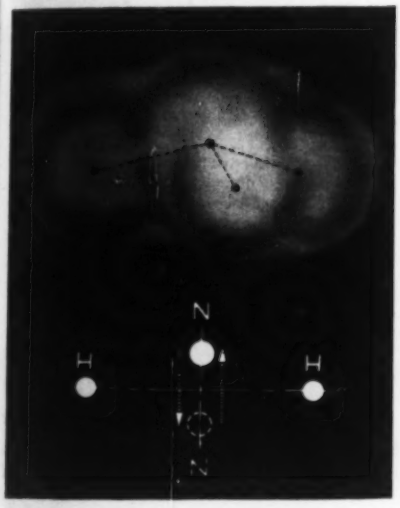
The present time and frequency standards are based on astronomical determinations of the period of rotation of the earth. However, the earth is being gradually slowed down by the forces of tidal friction in shallow seas. In addition, there are irregular variations —some of them rather sudden—in the period of rotation, the reasons for which are unknown. These two causes are responsible for changes in mean solar time and therefore in the frequency of any periodic or vibrating systems measured in terms of such time standards.

In recent years, vibrations of atoms in molecules—or, more specifically, spectrum lines originating in transitions between energy levels of these atomic systems—have been found in the microwave region of the radio spectrum. It has been possible to make extremely precise measurements of these lines by radio methods using equipment of unprecedented sensitivity and resolution. When it became evident that such spectrum lines might eventually provide new primary frequency standards, we scientists at the NBS began seeking a means of utilizing one of these lines to control an oscillator which in turn could be used to drive a clock. Because the resulting equipment, the atomic clock, is controlled by the invariable molecular system of ammonia gas, it is independent of astronomical determinations of time.

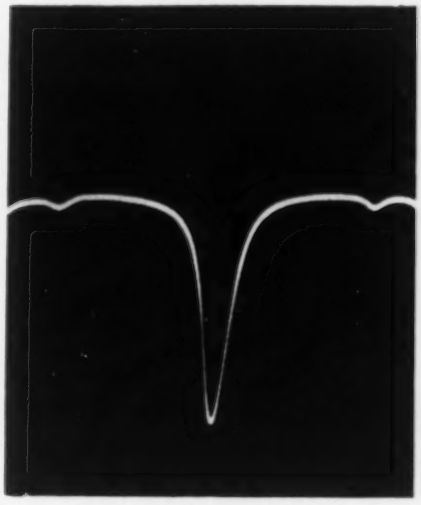
The NBS atomic clock consists essentially of a crystal oscillator, a frequency multiplier, a frequency discriminator, and a frequency divider, all housed in two vertical-type cabinet racks, on top of which are mounted a special 50-cycle clock and a waveguide absorption cell. Ammonia gas under a

FRONT-COVER PHOTOGRAPH

Dr. E. U. Condon (left), Director of the National Bureau of Standards and Dr. Harold Lyons, inventor of the NBS Atomic Clock, stand before the control panel of the clock. Dr. Condon is holding a model of the ammonia molecule whose microwave absorption line (shown on the oscilloscope screen at right) provides the invariant frequency which controls the timekeeping of the clock. The ammonia gas is maintained at low pressure in the 30-foot absorption cell wound around the synchronous clock (directly above the scientists).



The quantum transition by which the ammonia molecule (top), absorbing energy at one sharply-defined frequency, can turn itself inside out is illustrated in classical terms by the schematic diagram (bottom). An absorption line produced by such a transition serves as the frequency control for the NBS Atomic Clock. The ammonia molecule is in the form of a pyramid with a nitrogen nucleus at the apex and three hydrogen nuclei at the base; each nucleus is surrounded by its characteristic electron charge. The average distance between the nitrogen nucleus and each hydrogen nucleus is 1.01 Angstroms; that between the hydrogen nuclei is 1.63 Angstroms. The pyramid is about 0.38 Angstroms high, and the H-N-H apex angle is 107 degrees.



While the NBS Atomic Clock is in operation, the monitoring oscilloscope continuously displays a trace of the 3,3 absorption line of ammonia. The symmetric output pulse is produced by absorption of the FM control signal as it sweeps across the natural absorption-line frequency of the ammonia gas. The sharpness of this line on the 'scope screen is an indication of the timekeeping accuracy of the atomic clock. A frequency scale may be inferred from the known frequency interval (1.74 Mc.) between the main 3,3 pulse and the first satellite pulse on either side. This shows that the 3,3 absorption line width at the half-power points is about 0.335 Mc.; dividing the center frequency (23,870 Mc.) by this value yields a Q of 71,200.

pressure of 10 or 15 microns is maintained in this cell, a rectangular 0.50 in. by 0.25 in. copper tube wound in a compact 30-ft. spiral about the clock.

The new instrument uses an absorption frequency of ammonia to hold a microwave signal fixed. If the microwave signal output of a generator differs in frequency from the ammonia absorption line, then the control circuits generate an error signal which brings the microwave signal back to the frequency of the spectrum line. The oscillator generating the microwave signal is thus controlled, and the setting of the clock which it drives can be compared with an astronomical clock.

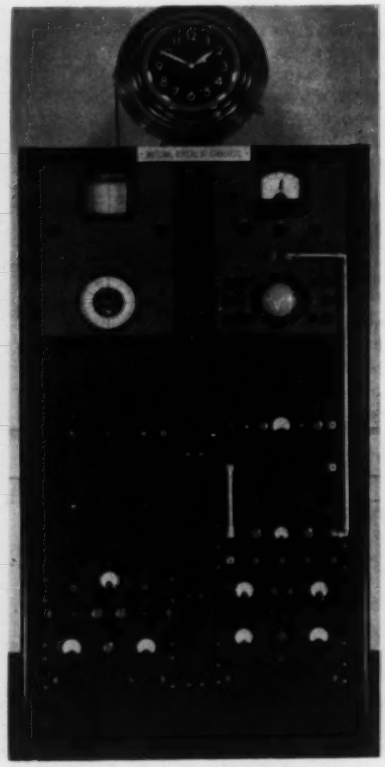
The microwave signal is initiated by a 100-kc. quartz-crystal oscillator or any other oscillator which, for purposes of convenience and accuracy, is designed for a high degree of stability. By means of vacuum-tube circuits and silicon-crystal diodes, this frequency is multiplied to provide output signals throughout the microwave range. These signals are compared with the frequency of a microwave spectrum line, in this case of ammonia gas, by suitable frequency-discriminator or servo control circuits. If the quartz-crystal oscillator drifts after the microwave signal at the upper end of the multiplier chain has been exactly tuned to the frequency of the spectrum line, the discriminator circuit generates an output signal which, through the proper control circuits, can be applied to the oscillator at the bottom of the multiplier chain to bring it back to the proper frequency. By means of a frequency divider, the 100 kc. may be reduced to any desired frequency for driving a clock; e.g. one thousand cyles or 50 cycles.

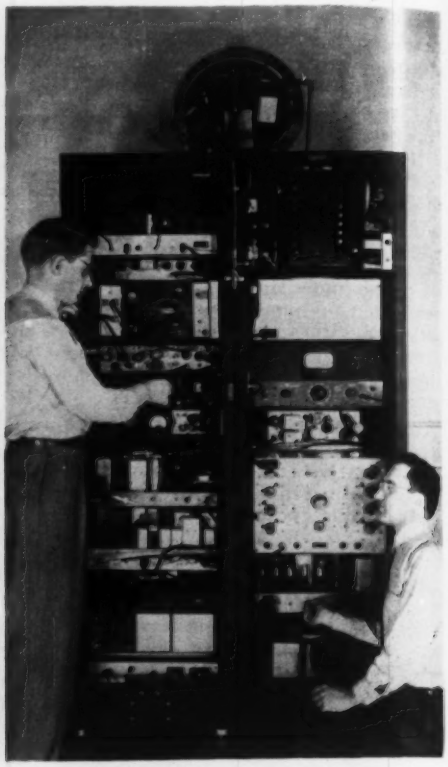
Principles and Operation

The control circuit in the present atomic clock is one successful form of several frequency-discriminator or servomechanism control circuits being developed by the NBS. It is now being refined to give even greater time-keeping accuracy.

The fundamental frequency signal generated by the 10-kc. oscillator is first multiplied up to 270 Mc. by a frequency-multiplying chain using standard low-frequency tubes. In the next step, the multiplying chain is continued up to 2970 Mc. by means of a frequency-multiplying klystron, which is also modulated by an FM oscillator generating a signal at 13.8 plus-or-minus 0.12 Mc. This makes the frequency-modulated output of the klystron 2983.8 plus-or-minus 0.12 Mc. After further amplification, the frequency-modulated signal is multiplied in a silicon crystal rectifier to 23,870.4 plus-or-minus 0.96 Mc., and fed to the ammonia absorption cell. As the frequency of this modulated control signal sweeps across the absorption line frequency of the ammonia vapor, the signal reaching the silicon crystal detector at the end of the absorption cell dips because of the absorption, thus giving a negative output pulse.

A second pulse is generated when the output of the frequency-modulated oscillator at 13.8 Mc. is fed to a mixer (or radio receiver) into which is also fed a 12.5-Mc. signal from the quartz-crystal multiplying chain. When the signal sweeps across the proper frequency to be tuned in (12.5 Mc. plus the 1.39-Mc. intermediate frequency of the receiver, or 13.89 Mc), an output pulse is generated. The time interval between the two pulses—that from the absorption cell, caused by the absorption line, and that from the receiver or mixer—is a measure of the degree to which the frequency-multiplying chain is tuned to the absorption line. The two pulses can therefore be made to control a discriminator circuit which will give zero output when the time interval is right (that is, when the circuit is tuned to the absorption line) and will generate a control signal when the time interval is wrong. If the quartz-crystal oscillator drifts in frequency to higher values, the time interval between the two pulses increases; for frequencies which are too l[illegible], the interval decreases. The control [illegible]gnals thus generated are fed to a rea[illegible]tance tube, which then forces the quart[illegible] crystal circuit to oscillate at the [illegible]orrect frequency to tune to the absorptio[illegible] line. The quartz-crystal oscillator i[illegible] thus locked to the ammonia line.





(Left)

The NBS atomic clock is completely contained in this unit with the wave-guide absorption cell wound in a spiral around a 50-cycle synchronous clock on top of the cabinet. From top of the cabinet. From top to bottom, on left panels: frequency deviation recorder; 1000-cycle synchronous clock (24-hour dial); electronic frequency meter (drives deviation recorder); 100-kc. quartz-crystal oscillator; frequency dividers (divide 100 kc. down to 50 and 1000 cycles); regulated power supply for klystron tubes; regulated plate and filament power supply. On right panels: frequency comparator and deviation indicator; monitoring oscilloscope; pulse amplifiers and shapers, and pulse discriminator; d-c. control voltage indicator; sweep generator, FM modulator, and klystron frequency multiplier (270 Mc. to 2984 Mc.); frequency multiplier (100 kc. to 270 Mc.); vacuum gage; regulated plate and filament power supply.

(Right)

General view of back of the equipment. E. F. Huston (left) and E. D. Heberling (right) are shown making adjustments on the clock's amplifier and power supply circuits. The amount of equipment shown is larger than needed for the clock alone since some of the instruments are for measurements and tests of performance. Actually, the circuits essential to the operation of the atomic clock could be condensed into one of the two cabinet racks.

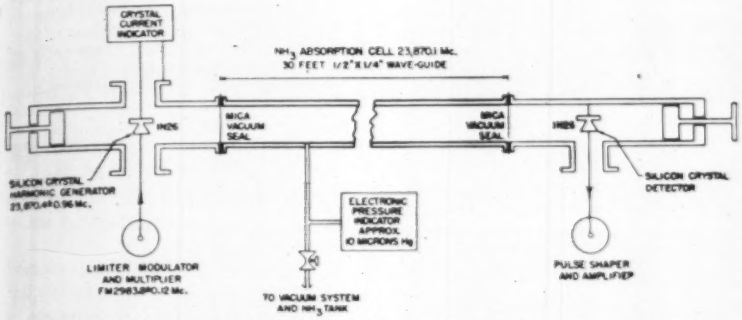
Frequency dividers then divide the precise 100-kc. signal down to 50 cycles to drive an ordinary synchronous motor clock, and also down to 100 cycles to drive a special synchronous-motor clock, which is designed for exact adjustment and comparison with astronomical time to within five milliseconds.

Control of the quartz-crystal circuit depends on the relative duration of the positive and negative portions of a square-wave signal generated by the discriminator. In the discriminator, the two pulses between which the time interval is to be measured turn a trigger circuit or square-wave generator on and off. When the time interval is correct, the on-off cycle generates no output

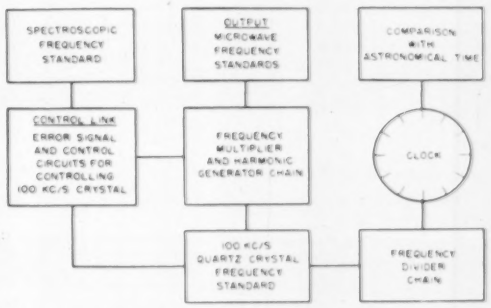
signal from the positive and negative peak detectors driven by the square-wave signal. The detectors or rectifiers draw current on the positive and negative peaks of the squarewave, but when the positive and negative portions of the square wave are of equal duration, they balance and give no d-c. output. However, if the time interval between the two input driving pulses gets longer or shorter, the relative durations of the positive and negative parts of the squarewave change, so that a resultant d-c. output is generated. This output is positive or negative, depending on the change in the time interval. Thus, no control voltage is generated when the quartz-crystal oscillator is on the proper frequency to agree, through the frequency-multiplying chain, with the ammonia line; but a positive or negative control voltage is produced for correcting the oscillator circuit when it drifts one way or the other from its proper value.

One great advantage of this particular clock circuit lies in the inherent short-time stability of the quartz-crystal oscillator, which makes it unnecessary for the discriminator circuits to apply correcting control signals to the oscillator at a rapid rate. The crystal and multiplier circuits bridge the gap between the frequency of the clock and that of the absorption line.

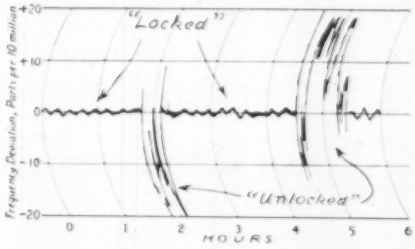
Recording equipment and a frequency meter are used in checking the accuracy of the clock. For this purpose, the frequency of the clock's crystal oscillator is compared to the frequency of the Bureau's primary frequency standards, a group of precision 100-kc. quartz-crystal oscillators calibrated in terms of the U. S. Naval Observatory time signals. These oscillators maintain constant frequency with respect to each other to an accuracy of one part in a billion for intervals up to ten hours, and better than one part in 100 million per day. They can therefore be used to measure the constancy of the atomic clock to this accuracy. This is done by beating the signals from the two sources together at a frequency of 12.5 Mc. to obtain greater measurement sensitivity. A change of one cycle per second in the frequency of the beat note, as recorded on the frequency meter or on an autographic recorder, indicates a frequency variation of one part in 12.5 million. In recent tests the clock maintained a constancy of one part in ten million for several hours. These tests show that the clock will lock accurately to the ammonia line even when a perturbng signal is applied to the reactance tube in a deliberate attempt to force the clock to change its rate.



The wave-guide absorption cell used in the NBS Atomic Clock is a rectangular copper tube wound in a compact spiral and provided with mica windows to seal in the ammonia gas at reduced pressure. A 2983.8-Mc. signal is fed through a coaxial cable to a type-1N26 silicon-crystal rectifier inside the wave-guide. This crystal rectifies the input current and generates strong harmonics which radiate down the wave-guide. Tuning plungers are shown at the input and output of the cells for impedance matching so that all of the signal is used and none reflected. The present 30-foot cell gives a two-to-one total reduction in signal amplitude. After passing through the absorption cell, the signal is received by another type-1N26 silicon-crystal rectifier. This rectifier, acting like a receiving antenna, generates an output current which dips by reason of absorption as the input frequency sweeps across the absorption-line frequency.


SPECTROSCOPIC FREQUENCY STANDARD
OUTPUT MICROWAVE FREQUENCY STANDARDS
COMPARISON WITH ASTRONOMICAL TIME
CONTROL LINK
ERROR SIGNAL AND CONTROL CIRCUITS FOR CONTROLLING 100 KC/S CRYSTAL
FREQUENCY MULTIPLIER AND HARMONIC GENERATOR CHAIN
CLOCK
100 KC/S QUARTZ CRYSTAL FREQUENCY STANDARD
FREQUENCY DIVIDER CHAIN

Simplified block diagram. The fundamental driving signal originates in the 100-kc. oscillator. The frequency-multiplier and harmonic-generator chain then multiplies this signal up to microwave frequencies. Frequency-discriminator circuits in the control link then compare the frequency of these signals with the ammonia frequency standard. Any tendency of the oscillator to drift will cause of discriminator circuits to send an error signal back to the oscillator, maintaining it at the proper frequency. The crystal oscillator is thus locked to the invariant frequency of the ammonia line. A frequency divider chain then drives a synchronous-motor clock.



Frequency-deviation record for a six-hour test run. Narrow portions, recorded while the clock was locked to the ammonia absorption line, indicate a constancy of one part in ten million.

Ultimate Accuracy

The ultimate accuracy of an atomic clock depends on many factors, of which the most important are those governing the width of the spectrum line. Spectrum lines have a finite width because atoms or molecules do not emit or absorb radiation at only one frequency but rather over a narrow band of frequencies. The ratio of a line frequency to its width at the half-power points—its "sharpness"—is called the Q of the line, in analogy to the Q (quality) factor of resonant circuits used in standard radio technique. In the case of ammonia, the natural line width determined by the uncertainty principle of quantum mechanics gives a Q of about 10^{18}. If a line width were determined only by the natural time of an excited state in the ammonia molecule, given a Q of 10^{18}, frequency and time could be determined to better than one part in a billion billion. However, the line is broadened by other factors which lower the Q to a value of 50,000 to 500,000, depending on the temperature and pressure of the gas. The ammonia spectrum line thus has a Q approximating that of the best quartz crystals, though much more constant and stable.

The ammonia molecules in the absorption cell are moving rapidly in random thermal motion at an average speed of almost 2000 fp.s at room temperature. When a gas molecule in an absorption cell is approaching or receding from the source of an electromagnetic wave because of its heat motion, its absorption frequency is different from that which it would have if it were standing still. This gives rise to a Doppler broadening of the absorption line, analogous to the change in pitch of sound as its source approaches, passes, and leaves an observer. Thus, the line width can be reduced slightly by lowering the temperature of the gas (or by using a heavier molecule). Doppler broadening lowers the Q of the ammonia line to about 330,000 at room temperatures.

Molecular collisions also broaden the absorption line. This broadening occurs because the collisions abruptly terminate the absorption process, causing the molecules to absorb wave-trains whose lengths vary in a random way determined by the distribution of time intervals between collisions. A frequency analysis of these wave-trains shows a corresponding random distribution of absorbed frequencies, all centering about a mean value determined by the number of collisions per second. In ammonia gas at a pressure of 10 microns,

Concluded on page 174

"HEAT INERTIA" *in* Problems *of* AUTOMATIC CONTROL *of* TEMPERATURE

By VICTOR BROIDA, Consulting Engineer, Paris, France

FOREWORD

Knowing that the new "electric brains" for rapidly solving control problems must be fed equations which state the problems exactly, some American instrument men have been learning how to feed their problems into computers. Meanwhile, in France, a brilliant engineer was devising a new—and amazingly simple — method of solving process-control problems without computers. It is a practical method of solving practical problems involving furnaces, stills, and even buildings (as Dr. Broïda has shown his enthusiastic followers in Europe). It can be mastered by anyone who has taken first-year differential equations.

Your editor is aware that the term "heat inertia" is taboo in English-language formal texts, but Dr. Broïda's method is based on his useful concept of the "fictitious mass" of a heat-process unit under automatic control; and so we let it stand in adapting his article for our American readers. In this work we had the valuable coöperation of Dr. J. C. Mouzon, Director of Research of the Brown Instrument Company.

M. F. Béhar

PART I

IT is easy to calibrate before installation, in an appropriate laboratory, an indicating or recording thermometer. On the other hand, it is nearly impossible to calibrate in a laboratory an automatic-control system comprising the controller itself and the valve or other device commanded by the controller.

The reason for this impracticability is the fact that two different processing units equipped with absolutely identical control instruments and valves or motors, set in the same way, will never behave in the same manner, because of their different respective inertias.

It follows that an automatic control device can be properly calibrated and set only in the field, taking into consideration the particular features of the unit under control, and that all that can be done in order to facilitate this setting in the field, is to provide the controller with some marks, determined beforehand in a laboratory and having no absolute significance.

The first—and already important—negative result of this fact is that the correct operation of an automatic instrument depends on a final calibration effected in the field and, therefore, under less favorable conditions than in a laboratory.

The second result is worse: the instrument man in charge of this calibration in the field, if he is aware of the features of the instruments he has to set, is not at all aware of the value of the particular inertia of the controlled unit—inertia which he is not only unable to measure but which he cannot even estimate in an approximate way. This instrument man is therefore obliged to rely on his personal experience and his professional intuition, which are excellent things but which are sometimes quite insufficient; frequent are the instances in which, despite all the professional skill, the comprehension and the good will of the instrument man, the automatic-control device, although correctly designed, operates in a manner utterly different from that intended, or even operates in the wrong direction.

This leads also to an abnormal situation in which highly-accurate instruments are frequently calibrated and set in the field by guesswork methods having no absolute value and the efficiency of which depends on the good sense of the staff in charge. This situation cannot be entirely avoided but it is obvious that important progress would be accomplished if it were possible to measure the particular inertia of the units equipped with automatic controllers or, at least, estimate this inertia in an approximate way.

What do we know exactly about inertia and, in the particular case under review, about heat inertia?

Mechanical inertia has been studied for a long time and there exists quite a number of analytical writings covering the fly-wheel and the various regulators based on centrifugal force; this is not the case with heat inertia, the reason for this being perhaps the fact that the regulators involved are of a more recent conception than speed regulators.

It is known that this heat inertia bears a part similar to that of a flywheel (whence the name "Heat fly-wheel" which is sometimes given to it) and that its amount is a direct function of the mass of the heat-process unit, just as in the case of the fly-wheel.

It is also known that this heat inertia has a favorable influence on units not provided with controllers—as it bounds the frequency if not the amplitude of temperature fluctuations—but that its influence is sometimes unfavorable on units equipped with controllers, as it opposes the action of the latter and creates a lag in this action.

The aim of this essay is to try to clarify this rather confused matter; we do not claim to give an absolute and final solution but rather suggest a scientific method of research, the elements of which are likely to be altered, as always, by practice.

Although the heat inertia of any unit is a direct function of its mass, we must consider that a furnace, a boiler or any other heating unit is composed of several different items such as brickwork, tubes, metal framework, tanks, water and steam contained in the boiler, fuel on the grate, etc., all of these items having very different masses, specific heats and temperatures. Under these conditions it is difficult if not impossible to make calculations on the basis of usual physical constants and to consider, for instance, the numerous items which constitute a heating unit as a single uniform item having a specific heat equal to the average of the specific heats of the different items composing this heating unit multiplied by their respective masses.

Apart from the complexity of such calculations and the necessity of repeating them for each separate unit (this alone being sufficient to deprive them of any practical use) such calculations would moreover run the risk of being wrong because of the very different heat conductivities of all the items which constitute the heating unit and of the resulting non-simultaneous variations of temperature in the different parts of the unit.

It would be therefore necessary—should we want to study beforehand the temperature variations occurring in a heating unit as a result of a given disturbance—to take into consideration not only the respective masses and specific heats of the different items composing this unit but also their heat conductivities, the respective positions of hot and cold surfaces, the temperatures of the latter, the nature of the space between them, the extent of the resulting transmission of heat by radiation, the velocities of the different fluids involved, their corresponding coefficients of convection, etc., and to determine, on the basis of all this information, the corresponding law of heat transmission under variable conditions.

Such a task is frequently impossible to undertake and in any case very complicated. Moreover, even though calculations of this kind can be of use to manufacturers of heating units in order to enable them to create units of new types, they are practically useless, owing to their complication, for users of these heating units or for manufacturers of automatic-control systems intended to control the units.

On the other hand, each heating unit must have some constant peculiar to the way in which it will behave when subjected to disturbances and it is easy to admit that this constant is not directly linked with the real mass of this unit obtained either by summing up simply the masses of the various items composing it or by summing up these masses after having multiplied each of them by the corresponding specific heat and by dividing the sum

thus obtained by the specific heat of one of these items, so as to obtain a mass of this item equivalent, from a heating standpoint, to the real average mass of the unit.

However, if the considered constant can have, as we said, no direct link with the real—total or average—mass of the heating unit under review, it corresponds nevertheless to some fictitious mass which would be for instance the real mass of an absolutely uniform heating unit behaving in the same manner as the considered heating unit when subjected to the same disturbances.

As a rule, such a fictitious mass cannot be calculated on the basis of usual physical constants nor be directly measured; it is however clear that it can be deduced from indirect tests of the unit by subjecting the unit to definite disturbances and by observing the way in which it will behave, as this way is peculiar to its fictitious mass.

In the following calculations (which, while starting on an entirely fictitious basis, will lead us to conclusions confirmed by automatic-control practice) we shall express the fictitious mass of a heating unit in kilograms or liters of water; this fictitious mass will therefore correspond to an equivalent real mass of water heated to the same temperature as that existing inside the heating unit and which would behave in an identical manner as the unit when subjected to the same disturbances. We shall consider the case of a hot-water boiler producing, in open circuit, a flow of q_1 liters of hot water per second at a temperature of θ_1 degrees Centigrade and we shall suppose that the flow of water drawn from this boiler is suddenly increased to a value of q_2 liters per second ($q_2 > q_1$). (It is obvious that we could consider just as well the case of a sudden decrease of the flow and that, on the other hand, we could consider, instead of a hot water boiler, a steam boiler or any other heating unit, the above example being chosen only in order to simplify the calculations.)

Furthermore, we shall call

m the fictitious mass of the considered heating unit, expressed in liters of water;

θ_0 the temperature of feed water, expressed in degrees Centigrade;

Q_1 the input of heat to the boiler per unit of time, expressed in kilocalories per second and

v the relative variation of the hot water flow drawn from the boiler,

such that:

$$v = (q_2 - q_1)/q_1$$

We shall now study, in the most general case, the variation of the temperature θ existing inside the heating unit, as a result of the disturbance to which it has been subjected.

The heating unit being in temperature equilibrium before this disturbance, the heat input to the latter per unit of time is equal to the heat output drawn from it with the hot water, or

$$Q_1 = q_1(\theta_1 - \theta_0)$$

The flow of hot water drawn from the boiler having suddenly increased, the temperature existing inside this boiler will decrease according to some function $\theta(t)$ of the time elapsed which we want to determine in different cases; simultaneously, the heat input to the boiler per unit of time, will either remain constant and equal to Q_1 (if the heating unit is not equipped with a temperature regulator) or will be altered (if this heating unit is provided with a regulator) and become a function of temperature and of time elapsed, such that:

$$Q = Q_1 + f(\theta, t)$$

the form of $f(\theta, t)$ having to be determined in each separate case.

In the particular case of a heating unit not provided with a temperature controller, we have obviously: $Q = Q_1$ and $f(\theta, t) = 0$.

At the moment t, the temperature inside the heating unit being equal to θ, the quantity of heat stored by the mass of this heating unit is equal to $m(\theta - \theta_0)$; at the moment $t + dt$ (the temperature decreasing, as a result of the sudden increase of the hot water flow drawn from the boiler, and having reached, at this moment, the value of $\theta - d\theta$) the quantity of heat stored by the heating unit is equal to $m(\theta - d\theta - \theta_0)$.

We can therefore write:

$$q_2(\theta - \theta_0)dt = -m d\theta + Q dt$$

Or, replacing Q by its general expression ($Q = Q_1 + f(\theta, t)$):

$$-m\frac{d\theta}{dt} = q_2(\theta - \theta_0) - Q_1 - f(\theta, t)$$

We have previously seen, on the other hand, that:

$$Q_1 = q_1(\theta_1 - \theta_0) \text{ from whence } q_1 = Q_1/(\theta_1 - \theta_0)$$

and that $v = (q_2 - q_1)/q_1$ from whence $q_2 = (v+1)q_1 = (v+1)Q_1/(\theta_1 - \theta_0)$

Replacing q_2 in the preceding equation by its value, we can write:

$$-m\frac{d\theta}{dt} = \left[\frac{\theta - \theta_0}{\theta_1 - \theta_0}(v+1) - 1\right]Q_1 - f(\theta, t) \qquad \ldots (1)$$

This is the law of variation of the temperature inside the heating unit, in its most general form.

Equation (1) has been obtained in the particular case of an increase of the flow of hot water drawn from the heating unit; we shall prove that this equation remains unchanged if this flow decreases suddenly instead of increasing and that it is thus obtained in a very general form.

Indeed, when $q_2 < q_1$, the temperature inside the heating unit increases and, at the moments t and $t + dt$, the quantity of heat stored by the mass of this unit is respectively equal to $m(\theta - \theta_0)$ and $m(\theta + d\theta - \theta_0)$, the corresponding temperatures inside the heating unit being respectively θ and $\theta + d\theta$.

It follows that, during the elementary time interval dt the mass of the heating unit receives a quantity of heat spent for increasing its temperature, equal to:

$$m(\theta + d\theta - \theta_0) - m(\theta - \theta_0) = m d\theta$$

The quantity of heat transferred by the source of heat to the heating unit during the same time interval dt and equal to $Q dt$ is, therefore, used, on one hand, to provide the hot water drawn from the boiler with the quantity of heat $q_2(\theta - \theta_0)dt$ which this water carries away during the same time interval and, on the other hand, to provide the mass of the heating unit with the quantity of heat $m d\theta$ spent for increasing its temperature.

We can therefore write:

$$Q dt = q_2(\theta - \theta_0)dt + m d\theta$$
$$\text{or } q_2(\theta - \theta_0)dt = -m d\theta + Q dt$$

which is exactly the same equation as that on which we have based in the particular case of increase of the flow of hot water drawn from the heating unit, namely equation (1).

It is also obvious that this equation can be extended to heating units other than hot water boilers; it is sufficient in order to do so, to replace the hot water flows q_1 and q_2, by the corresponding volumetric flows q_1' and q_2' of the considered fluid multiplied by the specific heat and by the density of this fluid.

Thus, if we call c the specific heat of the fluid and ρ its density, we can write:

$$Q_1 = c\rho q_1'(\theta_1 - \theta_0) \text{ from whence } q_1' = \frac{Q_1}{c\rho(\theta_1 - \theta_0)}$$

$$\text{and } v = \frac{q_2' - q_1'}{q_1'} \text{ from whence } q_2' = (v+1)q_1' = \frac{(v+1)Q_1}{c\rho(\theta_1 - \theta_0)}$$

The term $q_2(\theta - \theta_0)$, which, in this case, will take the form:

$$c\rho q_2'(\theta - \theta_0) = c\rho\frac{(v+1)Q_1}{c\rho(\theta_1 - \theta_0)}(\theta - \theta_0) = \frac{\theta - \theta_0}{\theta_1 - \theta_0}(v+1)Q_1$$

will therefore remain unchanged; so will be also the other terms of the general equation, as the values of the relative variation of the flow of fluid drawn from the heating unit v and of the heat input per unit of time from the source of heat to this unit Q_1 are independent of the nature of this fluid and as the fictitious mass of the heating unit m is expressed in liters of water.

It would be possible—just as we have extended, without alteration, Equation (1) to all the heating units, whatever may be the fluid used—to extend this equation, after altering it, of course, to the general instance of inertia and, particularly, to mechanical inertia existing in automatic control of pressures and flows and

which is a direct function of the mass of the fluid subjected to variations of pressure or flow.

Without entering into the details of such an extension we can state that Equation (1) on which this essay is based has been obtained by writing that the real quantities of heat produced by the source of heat and absorbed by the heated fluid were in balance with the quantities of heat yielded or absorbed by the fictitious mass of the heating unit, *i. e.* by its heat inertia.

The same equation of balance, extended to real mechanical forces, on one hand, and to mechanical forces of inertia, on the other hand, is none other than the equation which constitutes the principle of d'Alembert well known in mechanics; it will be, therefore, sufficient to use this principle—of which Equation (1) is, in turn, an extension to heating applications—to extend this equation to cases of inertia of units subjected to variations of pressure or flow and equipped with appropriate automatic controllers.

We shall use Equation (1) as a basis for studying the operation of heating units not provided with controllers or provided with automatic temperature controllers of various systems; we shall begin with the simplest case which is that of a heating unit having no controller at all.

In this case, the heat input to the heating unit per unit of time will remain, obviously, constant and equal to Q_1.

Equation (1) becomes, therefore, in the case of absence of any controller:

$$-m\frac{d\theta}{dt}=\left[\frac{\theta-\theta_0}{\theta_1-\theta_0}(v+1)-1\right]Q_1 \qquad \ldots (2)$$

In the particular case which is of interest to us—that of a sudden increase of the flow of hot water drawn from the heating

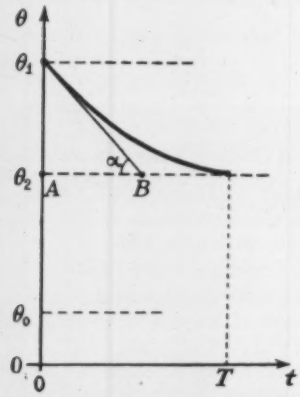


Fig. 1

unit—the temperature inside the unit will decrease, so that $\theta_2<\theta_1$ and the curve $\theta(t)$ will have the form shown in Fig. 1.

We shall determine, to begin with, the new temperature of stabilization θ_2; for this temperature $d\theta/dt=0$ as it corresponds to a state of balance. Equation (2) becomes, therefore, in this case:

$$\left[\frac{\theta_2-\theta_0}{\theta_1-\theta_0}(v+1)-1\right]Q_1=0$$

from whence

$$\theta_2=\theta_0+\frac{\theta_1-\theta_0}{v+1}=\frac{\theta_1+v\theta_0}{v+1}=\frac{\theta_1+v\theta_1-v\theta_1+v\theta_0}{v+1}$$

$$\text{and } \theta_2=\theta_1-\frac{v}{v+1}(\theta_1-\theta_0) \qquad \ldots (3)$$

This equation gives us also the following relation between $\theta_1-\theta_2$ and $\theta_1-\theta_0$ which will be useful to us later on:

$$\theta_1-\theta_2=\frac{v}{v+1}(\theta_1-\theta_0) \qquad \ldots (4)$$

We shall determine now the law $\theta(t)$ to which corresponds the curve of Fig. 1; in order to do so, we shall integrate the differential equation (2) between the limits θ_1 and θ, on one hand, and the corresponding limits 0 and t, on the other hand.

Separating variables and integrating gives us:

$$\int_{\theta_1}^{\theta}\frac{d\theta}{(\theta-\theta_0)(v+1)-(\theta_1-\theta_0)}=-\frac{Q_1}{m(\theta_1-\theta_0)}\int_0^t dt$$

$$t=-\frac{m(\theta_1-\theta_0)}{(v+1)Q_1}\log\frac{(\theta-\theta_0)(v+1)-(\theta_1-\theta_0)}{v(\theta_1-\theta_0)} \qquad \ldots (5)$$

This equation will be useful to us in the future.

It gives us immediately:

$$\frac{(\theta-\theta_0)(v+1)-(\theta_1-\theta_0)}{v(\theta_1-\theta_0)}=\exp\left[-\frac{(v+1)Q_1t}{m(\theta_1-\theta_0)}\right]$$

from whence:

$$\theta=\theta_1-\frac{v}{v+1}(\theta_1-\theta_0)\left\{1-\exp\left[-\frac{(v+1)Q_1t}{m(\theta_1-\theta_0)}\right]\right\} \qquad \ldots (6)$$

This is the equation of the curve $\theta(t)$ shown in Fig. 1.

Let us determine now the time T elapsed between the moments when the temperature is equal to its original value θ_1 and when it reaches its final stabilized value θ_2.

It is sufficient, in practice, to reach this limit with an approximation of 1°; we will therefore determine the time required for stabilization not for a temperature $\theta=\theta_2$ but for a temperature $\theta=\theta_2'=\theta_2+1°$.

Introducing in Equation (5) the value of:

$\theta=\theta_2+1=\theta_1-\frac{v}{v+1}(\theta_1-\theta_0)+1$, we obtain:

$$T=-\frac{m(\theta_1-\theta_0)}{(v+1)Q_1}\log\frac{v+1}{v(\theta_1-\theta_0)}=\frac{m(\theta_1-\theta_0)}{(v+1)Q_1}\log\frac{v}{v+1}(\theta_1-\theta_0)$$

Making use of Eq. (4),

$$T=\frac{m(\theta_1-\theta_2)}{vQ_1}\log(\theta_1-\theta_2) \qquad \ldots (7)$$

We must not forget that the time thus obtained corresponds to a variation of temperature between θ_1 and $\theta_2+1°$. Therefore, in accepting the above equation for the time it takes the temperature inside the heating units to pass from θ_1 to θ_2 we make a voluntary error of 1° Centigrade.

It can be stated, however, that this error is only 1% of the scale span of a chart calibrated from 0° to 100° (which is the case for charts used in recording hot water temperatures) and that it is of less than 1% when recording temperatures of fluids other than hot water (steam, hot air in industrial furnaces, etc.)

This error is therefore of the same order as the errors of measurement made in using most of the thermometers or pyrometers which measure and record temperatures of various fluids, with the exception of some very special instances. We can therefore use Equation (7) with a sufficient accuracy and use it in order to check the duration of disturbances by comparing it with practical results taken from a recorder chart.

From Eq. (7):

$$m=\frac{vQ_1T}{(\theta_1-\theta_2)\log(\theta_1-\theta_2)} \qquad \ldots (8)$$

We can also obtain the fictitious mass of the heating unit without being obliged to measure T or to determine the natural logarithm of $(\theta_1-\theta_2)$; we can use, instead, the following properties of subtangents to the curve $\theta(t)$.

If we examine formula (2), we will see that, if we make $\theta=\theta_1$ we find: $d\theta/dt=-vQ_1/m$.

This is the value of the slope of the curve $\theta(t)$ at the moment $t=0$—that is, at the moment the disturbance takes place—or, which is the same, of the slope of the tangent to this curve at the same point. It can be seen in Fig. 1 that:

$\tan\alpha=vQ_1/m$,

$$\text{and } m=\frac{vQ_1}{\theta_1-\theta_2}AB \qquad \ldots (9)$$

This very simple formula permits calculating m when Q_1 and v are known, by measuring on a recorder chart θ_1, θ_2 and the

Continued on page 158

ElectroniK

POTENTIOMETER

Story

Yours For The Asking!

There's a Brown ElectroniK Potentiometer with electric contact or proportional control for *every* temperature process. Every style . . . strip chart, circular scale, circular chart... is fully explained and described in new Catalog 15-13. Typical control systems, explanatory tables, and style selection data are included to help you choose the right instrumentation. Send for your copy today and you'll have *the complete story on the complete Brown ElectroniK line.*

MINNEAPOLIS-HONEYWELL REGULATOR CO.
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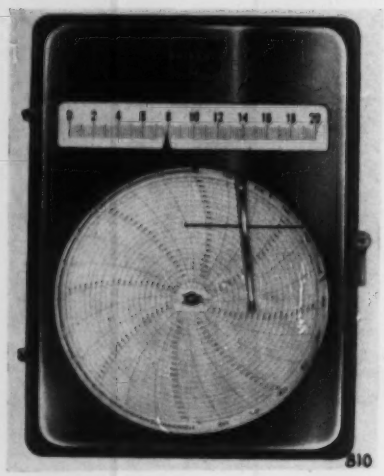
The Month's NEW INSTRUMENTS

In this department we report each month new devices for measurement, inspection, testing, metering and automatic control—in the form of concise technical descriptions.

FOR FURTHER INFORMATION USE THE POSTAGE-FREE ORDER CARD ON PAGE 187

Time-in-process Recorder

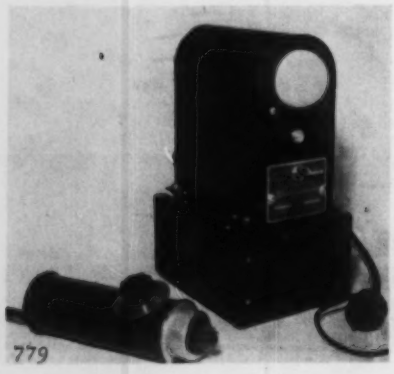
New time-in-process recorder gives a reading on a uniform scale and chart of rate of conveyor movement, directly in terms of total time consumed by work in traveling through a process; is useful where specifications for processing products are stated in terms of total time through process. (If conventional tachometer is used, operator must convert rpm. or fpm. into total time, which is difficult since time required for work to pass through a process depends not only on rate of movement but on length of path through process). New instrument simplifies problem of establishing correct conveyor speed for desired time-in-process; is suitable for continuous furnaces, continuous ovens, continuous ceramic kilns and continuous glass lehrs.—*The Bristol Co., Waterbury* 91, *Conn.*



Mention No. 201 when filling out card

Wide-range Vacuum Gage

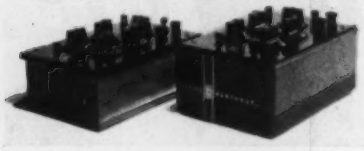
New "Type ANEW" vacuum gage and indicator incorporates gas-discharge tubes which greatly extend range and selective point vacuum control. Instrument incorporates power cabinet with high voltage transformer, base with thyratron relay, and sensing tubes which may be (a) fixed point tubes pre-set to throw relay at specific degree of vacuum or (b) so that control point can be varied over 1 mm. to 100 mm. (or 100 microns to 20 microns, etc). Range of control is 100 mm. Hg to 5 microns absolute. Sensitive to concentration changes and will hold vacuum on dynamic systems to plus or minus 1 percent.—*Skaneateles Mfg. Co., Inc.*, 122 *Dickerson St., Syracuse* 2, *N. Y.*



Mention No. 202 when filling out card

Metal-cased Laboratory Instruments

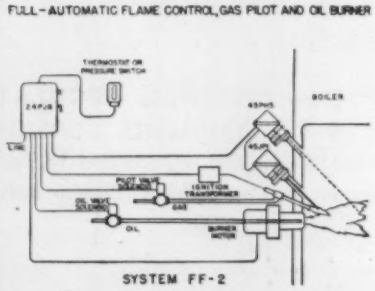
New metal cases for maker's laboratory instruments are announced. Example illustrated is "Enclosed Switch Wheatstone Bridge," before and after case redesign. Not only more modern than mahogany in appearance, new metal case is sturdier and better able to stand rough handling. — *Leeds & Northrup Co.*, 4984 *Stenton Ave., Philadelphia* 44, *Pa.*



Mention No. 203 when filling out card

Flame Failure Safeguard

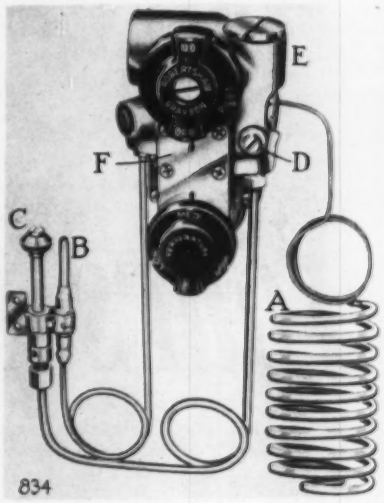
New system prevents explosions of industrial oil burners by supervising both pilot and main oil flames. Consists of "Type 45JP1" electrical flame rod which "feels" pilot flame and signals "Type 24PJ8" programming control. "Type 45PH5" photoelectric scanner monitors main flame and sets oil valve delay and post ignition periods in matter of seconds.—*Combustion Control Corp.*, 77 *Broadway, Cambridge* 42, *Mass.*



Mention No. 204 when filling out card

Combined Room Thermostat and Pilot-type Safety Shut-off

New "Room Temperature Unitrol" combines a gas thermostat, main valve and pilot into one assembly said to be "revolutionary" and designed for factory installation in heater so that local dealer need only connect the heater and light it. Temperature-control portion has "supersensitive" 60-inch bulb (A) which is normally located in cold-air return and operates main gas valve through maker's "Hi-lift" positive snap-action mechanism. Operating differential is less than three degrees. Safety portion comprises maker's "Super-clad" thermocouple (B) said to have been "proven in millions of installations." Thermoelectric current energizes an electromagnet which holds valve in operating position as long as pilot flame remains lighted. In event of pilot flame failure, electromagnet releases, causing all gas valves to close. Pilot burner (C) has tip, flame-shield and orifice of stainless steel. Pilot valve and adjuster (D) is downstream from cartridge-type pilot filter (E). Removable plate (F) provides access to entire interior of valve chamber.—*Grayson Controls Div., Robertshaw-Fulton Controls Co.*, 3000 *Imperial Highway, Lynwood, Calif.*



Mention No. 205 when filling out card

Magnetic Strain Gage

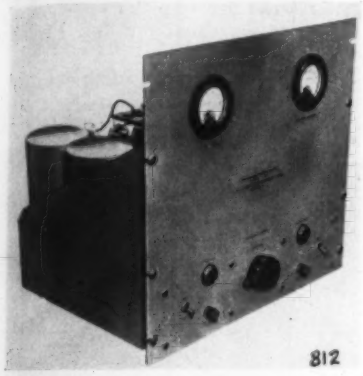
New magnetic strain gage provides a simple method of directly measuring small distortions in a static member under tensive or compressive load; is particularly useful as a warning to operator when a crane is in danger of upsetting due to overloading, or on other metal structures where variations in load may approach safe limits of the supporting member. Unit consists of

strain gage enclosed in a water-tight case 3.5 by 8.25 by 3.25 in. and pilot bar rigidly mounted on supporting member; and indicating instrument located wherever desired. Ultimate sensitivity, 20 lbs. Operation is from single-phase 110-volt 60-cycle supply; voltage and frequency variations should not exceed 3 percent; power required, 35 va.—*Westinghouse Electric Corp., Box* 868, *Pittsburgh* 30, *Pa.*

Mention No. 206 when filling out card

Regulated Power Supply

New "Model E-48" laboratory type regulated power supply is designed for standard relay rack mounting or may

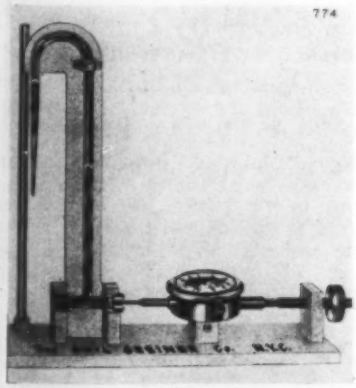


be housed in a suitable cabinet for bench use. Specifications: Input, 105-125 volts, 60 cycle, 750 watts. Output variable 160 to 1500 volts, 125 ma. dc. Ripple less than 0.05 volts peak-to-peak. Regulation less than 0.15 percent variation in output from no load to full load. Less than 0.015 percent variation in output voltage per volt of primary source. — *Chatham Electronics*, 475 *Washington St., Newark, N. J.*

Mention No. 207 when filling out card

Microburette

New "Gilmont" ultra-microburette now features special swivel micrometer attachment to facilitate operation;



crank handle to increase titration speed, and improved stand and attachments. In use, precision plunger displaces mercury which in turn forces minute exact amount of titrant through orifice immersed in solution being analyzed.—*The Emil Greiner Co.*, 20-26 *N. Moore St., New York* 13, *N. Y.*

Mention No. 208 when filling out card

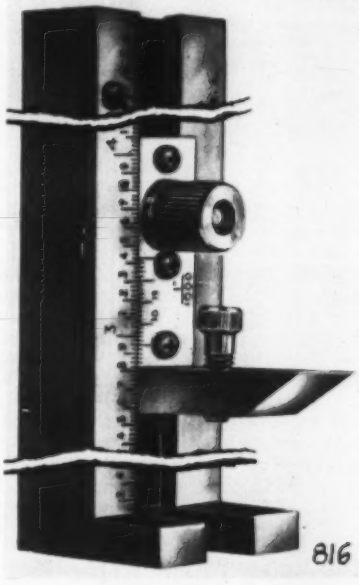
Miniature Industrial Electron Tube

New "Type GL-5610" 7-pin miniature electronic tube for industrial applications may be used to operate a relay in a circuit for heating control or other industrial operations. Under maximum ratings, plate voltage is 300 volts. Plate dissipation, 3.0 watts. Typical operation characteristics include: heater voltage, 6.3 volts; plate current, 17 ma.; plate resistance, 3500 ohms. Maximum overall length, 2.125 in.; seated height, 1.875 in. — *Tube Divisions, General Electric Co., Schenectady, N. Y.*

Mention No. 209 when filling out card

Multi-purpose Height Instrument

New adjustable vernier size block is designed to take place of instruments such as height, planer, inside vernier



caliper; space, feeler and surface gages; square; jack; and "5850 combinations of size blocks in 0.001-in. readings." It is suited for setting tool heights, stops and trips; sine bars, snap gages, dial indicators, etc. Scales are adjustable. A thumbscrew on platform accommodates arm of dial indicators. Illustration is full-size with portions suppressed; height 7 in.—*Barr Instrument Co.*, 134-39 225*th St., Springfield Gardens* 13, *N. Y.*

Mention No. 210 when filling out card

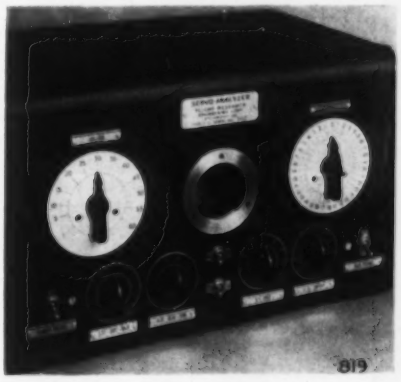
R-f Z-angle Meter

New "Type 311-A" Z-angle meter measures impedance and phase angle at radio frequencies, is said to eliminate need for computations, and has self-contained balance indicator. Instrument is direct reading over frequency range of 100 kc. to 2 Mc., impedance range of 10-5,000 ohms, and phase angle 0-90 deg. Sign of phase is noted by pressing button.—*Technology Instrument Corp.*, 1058 *Main St., Waltham* 54, *Mass.*

Mention No. 211 when filling out card

Automatic-control-system Analyzer

New "Type 5 Servo Analyzer" is a modification of "Type 2" described in our June 1948 issue, page 510. It is a general-purpose servo test instrument for mearusing dynamic response of d-c. or 400-cycle a-c. servomechanisms, servo

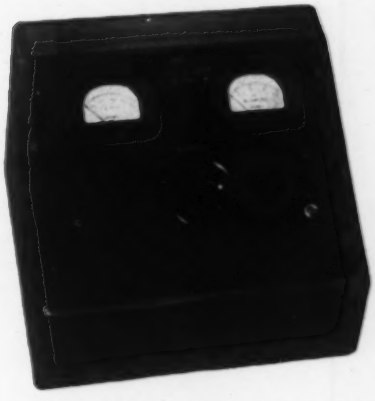


amplifiers, and networks. Disturbing and reference voltages for obtaining frequency response or transfer function are provided over frequency ranges from 0.1 to 6 cps. and 1 to 60 cps. by a two-speed gear. Disturbing and reference outputs may be changed from suppressed carrier 400-cycle voltages to sinoidally varying "d-c." voltages by turning a panel switch. When connected to a servo system under test it provides data which otherwise could only be obtained by lengthy computations or graphical methods.—*Flight Research Engineering Corp., P.O. Box* 1-*F., Richmond, Va.*

Mention No. 212 when filling out card

A-c. Insulation Tester

New "Model 2402" tester is high-potential type for measuring breakdown voltages of insulating materials, com-

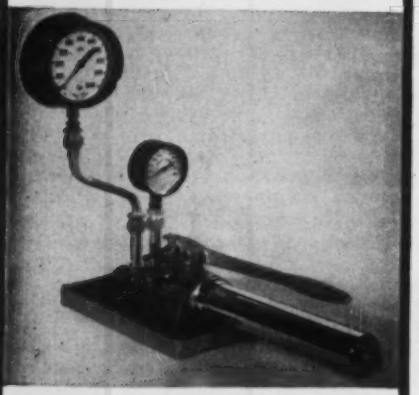


pounds and liquids. Recommended for use in testing appliances, cable assemblies, etc. Instrument has built-in variable autotransformer that provides stepless control of potential applied in test. Direct-reading voltmeter is connected across output; milliammeter indicates current flow as test proceeds, also exact point of breakdown (by abrupt rise in current). Unit contains all essential parts and is furnished with 5-ft. high-voltage cable and 6-ft. a-c. cord. Output voltage: 0 to 2,000; current max. 25 milliamps.; scale length,

WHY BUY
3 UNITS
when
1 TWIN SEAL UNIT
WILL SERVE 3 WAYS

10,000 psi—no leakage or seepage

1 PORTABLE PRESSURE TESTING
Weight, filled with oil, 8½ lbs.



2 BENCH WORK WITH TEST GAGE
mounted on aluminum drip pan

3 DEAD WEIGHT TESTING
shown with dead weight attachment mounted on unit.
Write for Bulletin

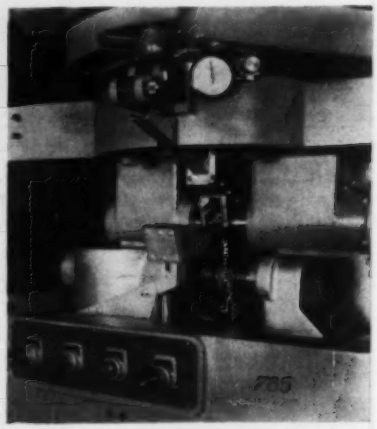
MANSFIELD & GREEN
1051 Power Avenue CLEVELAND 14 O

2.22 in.; accuracy, 2 per cent of full-scale value.—*Cole Instrument Co.*, 1320 *S. Grand Ave., Los Angeles* 15, *Calif.*

Mention No. 213 when filling out card

Semi-automatic Gaging Combined with Automatic Loading

New semi-automatic gaging device has been added to maker's automatic loaders for gear finishing machines.

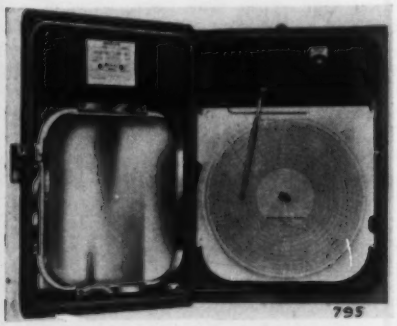


Device mounts at loading end of chute leading into machines. It consists of two gears that gage pinions being finished and mounted so that they can revolve freely. Center distance between two gaging gears is such that pinion with oversize pitch diameter, or one on which stock is excessive for best shaving results, will not drop through between gears into chute. Pinions are picked up singly by automatic adaptors, shaved and ejected into exit chute.—*Michigan Tool Company*, 7171 *E. McNichols Road, Detroit, Mich.*

Mention No. 214 when filling out card

Running Count Recorder

New running-count recorder plots on circular chart, a curve of number of operations against time. It records total



count of intermittent operations and time at which each one occurs. On production machinery it records work-producing operations or number of pieces produced. Total number of operations or pieces produced can be found by multiplying number of complete pen traverses across chart by count-per-traverse for which instrument is calibrated. Hourly rate of production, as read from chart, gives information regarding effect of fatigue on operators, variations between operators, etc. Excessive down time is easily read on chart. Instrument can be used as basis for paying production employees.—*Bristol Co., Waterbury, Conn.*

Mention No. 215 when filling out card

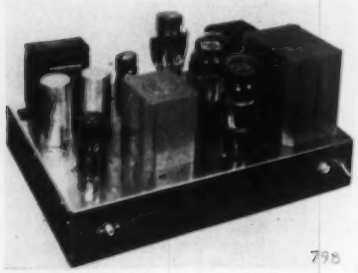
High-voltage Resistor

New "Type BTAV" resistor, variation of maker's "BT," withstands 2,000 volts in continuous use and surges up to 6,000 volts. Recommended for high-voltage applications such as discharge resistor across capacitors in flourescent ballasts, in television bleeder circuits and as instrument multiplier. Internal part of resistor lead wires is shorter leaving wide air gap between ends.—*International Resistance Co., Philadelphia, Penna.*

Mention No. 216 when filling out card

Amplifier

New "Model AA-20" high-fidelity medium-power all-triode amplifier is companion unit to maker's "RJ-20" high-

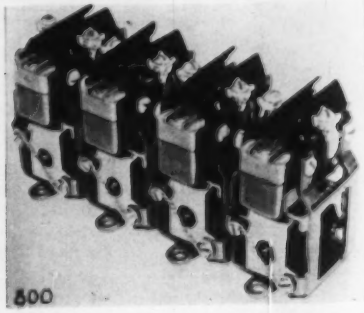


fidelity FM-AM tuner. New instrument features all-triode voltage gain and power stages for response within 1 db from 10 to 17,000 cps. with less than 1.5 per cent harmonic distortion at 14 of rated 15-watts output. Hum level is 65 db below maximum rated output. Output stage is pushpull "6B4G's" driven by two triode sections of "6SN7" in cascade with separate bias rectifier. Weight, 23 lbs.—*Browning Labs.*, 750 *Main St., Winchester, Mass.*

Mention No. 217 when filling out card

A-c. or D-c. Relay

New "Diaphlex" miniature aircraft relay can be assembled with others as shown in illustration. All terminals are arranged on common level for convenience and simple wiring harness. Re-



lay is 2.75 in. overall length, 1.3125 in. wide, by 2.375 in. high and weighs 4.5 oz. Main supports are of anodized aluminum. Electrical characteristics: coil, 150 ohms, 28 volts, d.c.; switch, snap action with magnetic blow out s-p.s-t., normally open rated at 10 amp. 110 volts, d.c. inductive. Relay has self-aligning coil terminal lugs, high voltage insulation, and is suitable for operation from minus 65 to plus 160 deg. F.—*Cook Electric Co.*, 2700 *Southport Ave., Chicago* 14, *Illinois.*

Mention No. 218 when filling out card

Metal Recording Chart

New metal recording chart is said to be superior because it withstands extreme conditions of temperature, pressure, etc., and will not shrink, expand,

deteriorate or deform in use even when in contact with moisture, hydrocarbons, etc. Chart also is advantageous since special coating responds to light stylus or dry pen and no retouching is required before reproduction. Chart has proved successful when immersed in oil well tubing. Furnished in thicknesses of 0.002 to 0.003 in. in roll, strip, circular or special shapes. (0.001 to 0.0015 in. also available).—*Otis Pressure Control, Inc., Box* 7206, *Dallas, Tex.*

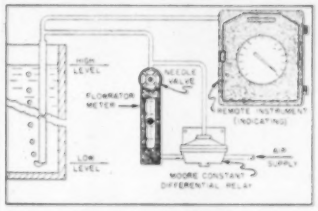
Mention No. 219 when filling out card

Combination C-r. Oscilloscope and Sweep Generator

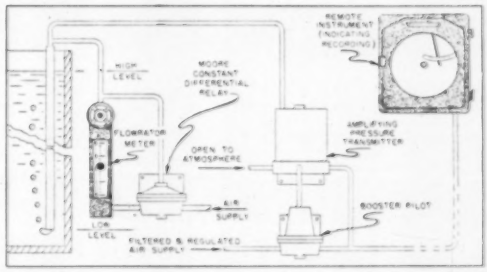
New "Vee Dee 90" combines in one instrument oscilloscope and sweep generator, weighing only 25 lbs. and meas-

Now..FLOWRATOR meters solve LIQUID LEVEL & SPECIFIC GRAVITY metering problems

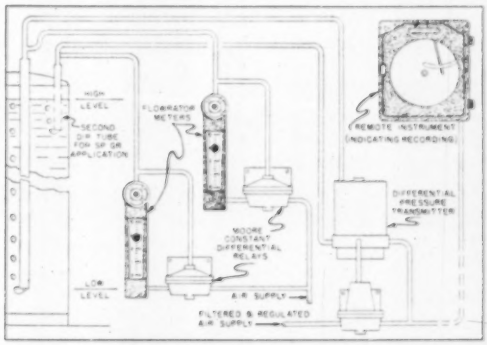
Liquid Level Measurement in an Open Vessel



Liquid Level Measurement in Open Vessel, with Amplifying Transmitter



Liquid Level or Specific Gravity Measurement in a Pressure Tank



The "C-Clamp" style FLOWRATOR meter was developed specifically for doing away with the bubbling bottle nuisance for purge line service and control instrument air supply. It replaced tedious and inaccurate bubble counting with direct immediate metering; replaced a bulky device containing a liquid filled bottle with a compact little instrument easily nested together on instrument panels.

Now this same "C-Clamp" style meter has been teamed with the Moore Products Constant Differential Relay to measure liquid level and specific gravity in open vessels and also in closed ones where a small bubble stream of air is not deleterious.

For complete construction details write for catalog 30

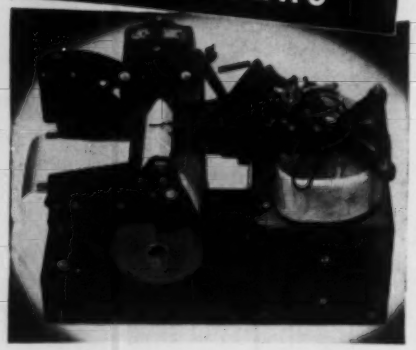
FISCHER & PORTER CO.

DEPT. 9M-5C HATBORO, PA.

FLOWRATOR

TRADEMARK

DIRECT WRITING RECORDERS



Galvanometer available separately if desired

PERMANENT Records
•
NO INK
•
RECTILINEAR Writing
•
RUGGED Construction with EXTREMELY HIGH torque movement (200,000 dyne cms for 1 cm deflection)

While designed primarily for use in the Sanborn direct-writing electrocardiograph (the Viso-Cardiette) this assembly (or the galvanometer alone, if desired) has sufficient potential value for varied industrial applications to warrant this announcement of availability for non-medical uses.

The complete unit illustrated comprises the galvanometer and writing arm, with associated paper drive (No. 572M – 500). The galvanometer and writing arm are available as a separate unit (No. 572M – 300). Recording styli available in two types; fine line writing approximately 1/3 mm; wide line writing approximately 1 mm. Recording paper can be furnished in 200 ft rolls, 6 cm wide (No. 572-737-P3).

TABLE OF CONSTANTS

Sensitivity	10 ma/1 cm.
Coil resistance	3,000 ohms, center tapped for push-pull operation.
Critical damping resistance	500 ohms.
Undamped fundamental frequency	45 cycles/sec.
Stylus heater requires from external source	1.25 volts, 3.5 amps, AC or DC
Maximum undistorted deflection	2.5 cm. each way from center
Marker requires from external source	1.25 volts, at 1.5 amps, AC or DC
Paper speed	25 mm/sec.
Chart ruling	1 mm intervals

In the development stage are other Sanborn "medical recording" instruments which have apparent industrial applications. These include an Electromanometer for direct measurement of "pressures", and several models of multi-channel (2 to 6) recorders, both direct recording and photographic.

For descriptive bulletin write to

INDUSTRIAL DIVISION
SANBORN COMPANY
39 Osborn St.
Cambridge 39, Massachusetts

uring 14 x 18 x 12.5 in. Oscilloscope has standard characteristics with its own sinoidal sweep generator. Sweep generator has continuously variable band width 50 kc. to 60 Mc. with range of 4.5 to 30 Mc.—*Radio City Products Co., 152 West 25th St., New York, N. Y.*

Mention No. 220 when filling out card

Governor for Instrument-mechanism Speed

New "Universal Timing Governor" is a self-starting (but not self-powered) precision escapement unit hermetically

sealed in two-inch stainless-steel case with transparent cover. All moving parts are visible. Three equally-spaced ears integral with base stamping are used to mount unit to three posts with a simple clockwise twist, snapping case into position. Standard unit is 1-hour rotation control; various other time rotations will be available. Power for operation may be supplied through output shaft. — *Precision Products, Inc., 516 S. Lansing, Tulsa 5, Okla.*

Mention No. 221 when filling out card

Radioactivity Demonstrator

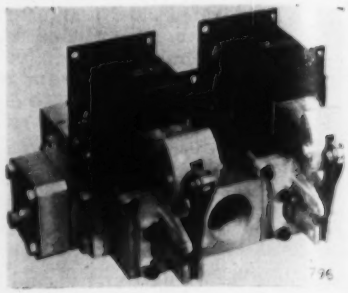
New "Type SU-4" radioactivity demonstrator is principally designed as inexpensive teaching aid. It indicates ra-

diation by (1) loudspeaker, (2) flashing neon tube, or (3) quantitative rate meter (up to 2500 counts per min.). Outfit includes built-in Geiger tube to detect gamma and high-energy beta rays. Tube voltage can be varied from 500 to 11 volts; instrument operates on 110 volts a.c.—*Tracerlab, Inc., 55 Oliver St., Boston 10, Mass.*

Mention No. 222 when filling out card

Dual-pressure Selector Valve

New electrically-operated dual pressure selector valve, incorporates maker's "Shear-Seal" principle and result-

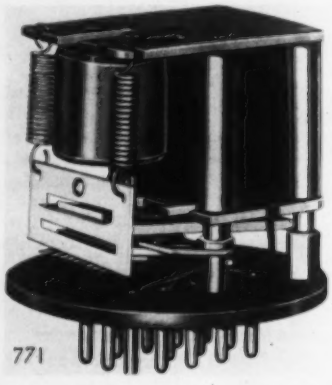


ant low handle loads, which permit direct solenoid actuation of valve. Pilot lines are eliminated, saving space. Designed for water pressures to 7000 psi., valve may also be used on oil or air. Accommodates screwed, welded, or flanged connections up to 2 in. on pressure ports and 2.5 in. on return port. —*Saval, Inc., 1915 East 51st St., Los Angeles 11, Calif.*

Mention No. 223 when filling out card

Rheostatic Regulator

New "Regohm" rheostatic regulator of direct-acting finger type is improved model which regulates voltage, current,

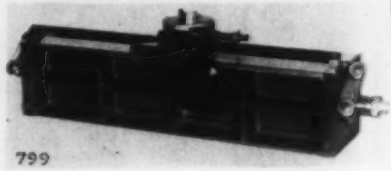


speed of motors and other rotating devices. Instrument now available in normally open or closed models, has redesigned magnetic circuit, new long-life contact materials, hermetically-sealed enclosure and operates on 1 watt d.c. Sensitivity is such that plus or minus 2 per cent change in solenoid current drives 'Regohm" through its range.—*Electric Regulator Corp., 1938 Park Ave., New York 35, N. Y.*

Mention No. 224 when filling out card

Slotted Line

New "Type 805A" slotted line for microwave measurements substitutes two parallel planes and rigid central circular conductor for conventional co-

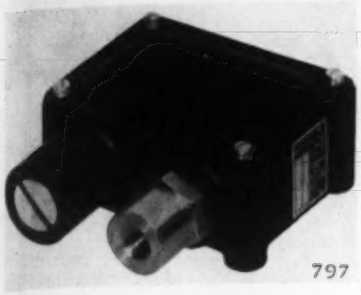


axial arrangement, and is said to be superior because planes can be made mechanically rigid, and central conductor is proportionally smaller. Depth of probe penetration is much less critical and carriage inaccuracies are minimized. Slot opening is less than 0.001 in. referred to coaxial system.—*Hewlett-Packard Co., 395 Page Mill Rd., Palo Alto, Calif.*

Mention No. 225 when filling out card

Pressure Switch

New pressure switch makes or breaks electrical connection when hydraulic fluid reaches predetermined pressure

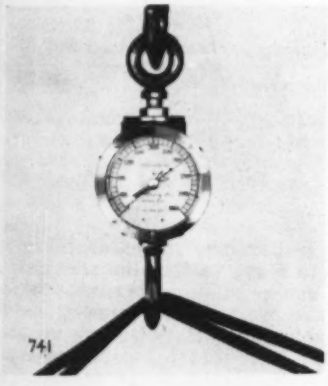


on pumps, automatic hydraulic machines or presses. Available in 6 pressure ranges from 50 to 10,000 psi. for water, oil, or air service. For a.c. or d.c. with normally-open or normally-closed circuit. Actuating pressure setting may be adjusted and locked externally. Hydraulic connection tapped with 0.25 in. pipe thread. Switch housing drilled for 0.5 in. conduit connection.—*Saval, Inc., 1915 East 51st St., Los Angeles 11, Calif.*

Mention No. 226 when filling out card

Scale for Cranes and Hoists

New "Hydroscale" is said to have "no springs or levers . . . permanently sealed, without moving parts, unaffected



by temperature, . . . accurate within one-half of one percent." Two-ton model immediately available; five- and ten-ton models in thirty days.—*Hydroway Scales, Inc., 7632 Fenkell Ave., Detroit 21, Mich.*

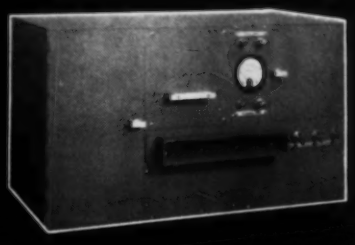
Mention No. 227 when filling out card

Miniature Inclined-tube Pressure Gage

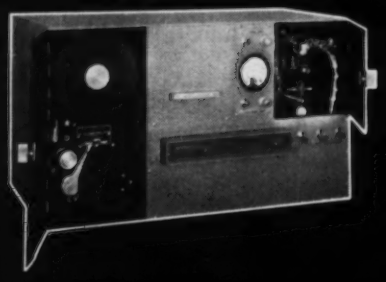
New miniature pressure gage for measuring fractional-inch pressures is particularly suited for indicating pres-

Century

FOR A PERFECT RECORD



— Vibrations —
— Sounds —



— Pressures —
— Temperatures —

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- The famous Century pencil-type galvanometers, 4 to 28 hermetically sealed elements — wide selection of natural frequencies to 5,000 cycles per second — high factors of sensitivity and balance.
- Governor controlled paper drive motor adjustable ± 20% fixed speed — gear shift transmissions with automatic lamp intensity device.
- Temperature compensated tuning fork — discharge lamp imposing sharply defined .01 second lines with heavy .1 second lines.
- Daylight loading 200 ft. storage and takeup magazines — accommodate 2" to 8" paper widths.
- Available with following optional features:
  Paper speeds to 50 inches per second — Automatic record length control — Automatic record numbering — Sweep scanning — Footage indicator — Trace identification — Remote control — 12-volt d.c., 24-volt d.c., or 110-volt a.c. operation.

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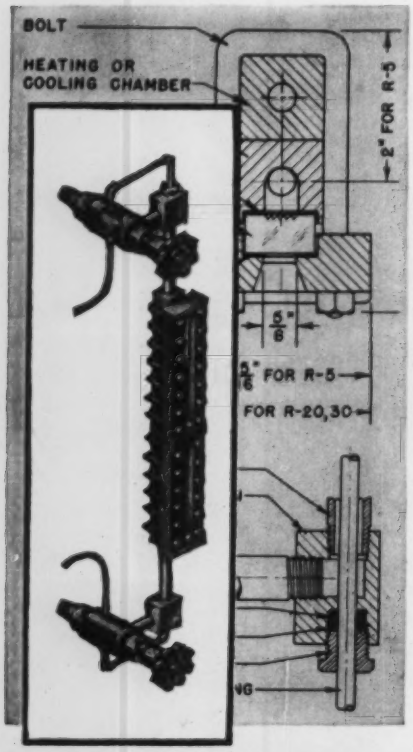

JERGUSON HEATED AND COOLED GAGES

Give Accurate Readings Under All Conditions

USE Jerguson Heated Gages for accuracy if you are dealing with high viscosity liquids that flow sluggishly.

On the other hand, if you are dealing with highly volatile liquids which tend to boil, use Jerguson Cooled Gages with circulating cooling medium.

In either case, Jerguson engineers have the answer, with a complete line of gages that give accurate reading of *all* liquids under *all* temperature conditions.

Jerguson Heated-Cooled Gages are made in internal tube and double chamber models for all pressures.

Illustration shows Internal Tube Model, Reflex Type, with No. 93 Valves. Write for Data Unit No. 17.

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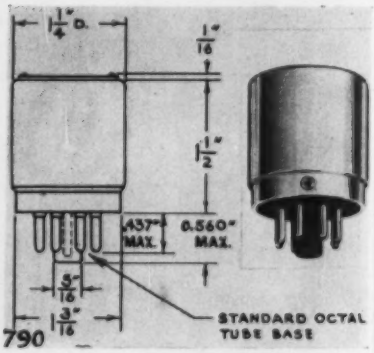
sure drops in filters and pressure changes due to chemical reactions in closed vessels. Employs spirit level pivoted at one end and made movable by slack diaphragm. Range 0.25 to 2 in. Scale length, 2 in. Furnished with 0.125 in. threaded connections.—*Seico, Inc., 10210 South Hoyne Ave., Chicago 43, Ill.*

Mention No. 228 when filling out card

Crystal Oven

New "Type TCO-1," crystal temperature stabilizer, is designed for use with maker's "Type BH6" crystal units

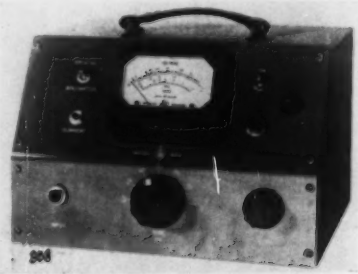


which mount in internal socket to provide frequency stability down to plus or minus 0.0001 per cent while crystal temperature is maintained within 2 deg. C. Standard unit is supplied for operation at 75 deg. C. and is equipped with 6.3 volt heater rated at 5.5 watts. —*Bliley Electric Co., Erie, Pa.*

Mention No. 229 when filling out card

Standing Wave Indicator

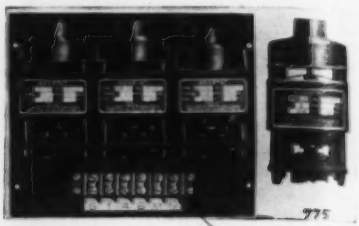
New "No. 415A Standing Wave Indicator" measures relative audio voltages detected by a crystal rectifier or bolometer, is designed for use with maker's "805A Parallel-plane Slotted Line," may also be used with other slotted line systems. It consists of a high-gain amplifier having low noise level and operating at a fixed audio frequency. Output of amplifier is measured with a square-law indicating VTVM calibrated both in decibels and in voltage standing wave ratio. Input circuits are provided for use with either a crystal or barreter.—*Hewlett-Packard Co., 395 Page Mill Road, Palo Alto, Calif.*



Mention No. 230 when filling out card

Proportional Time Delay Relay

New "Agastat" proportional time delay relay for radio and television transmitters provides 1 minute initial time

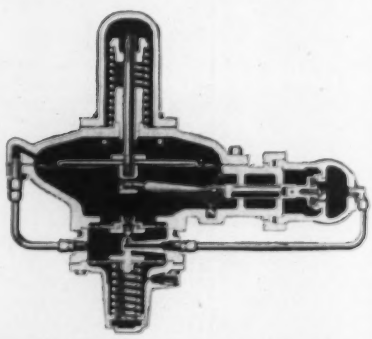


delay after coil is energized. In power failures up to 15 seconds, circuit is re-established instantaneously. Above 15 seconds, upon restoration of power, time delay proportional to length of power failure takes place, permitting transmitter to go back into service quicker. Combination unit of two proportional and one standard "Agastat" makes possible proportional time delay up to 5 minutes or more.—*Agastat Div., American Gas Accumulator Co., 1029 Newark Ave., Elizabeth 3, N. J.*

Mention No. 231 when filling out card

Multi-purpose Gas Regulator

New "Type 99" multi-purpose gas pressure regulator is set to be extremely stable in operation over entire pressure and volume range, enabling operator to serve various installations with only one regulator. Available in 2 in. screwed pipe thread connections only. Suitable for inlet pressures up to 150 psi. and reduced pressures of 0.25 to 50 psi. Capacity range is from 0 to 143,000 cfh.—*Fisher Governor Co., Marshalltown, Iowa.*



Mention No. 232 when filling out card

Automatic Inspection Equipment for Crankshafts

New gaging machine using twenty "Precisionaire" tubes checks automobile crankshafts for size and out-of-round. Five main bearings are checked simultaneously with five "Airsnaps," each having three sets of jets so as to gage midway between flanges and 0.125

in. from each flange. These "Airsnaps" are floated so that they more forward and backward to allow for misalignment due to possible warpage in crankshaft. Two other "Precisionaire" jets check seal diameter at one place and width of rear main bearing.—*The Sheffield Corporation, Dayton 1, Ohio.*

Mention No. 233 when filling out card

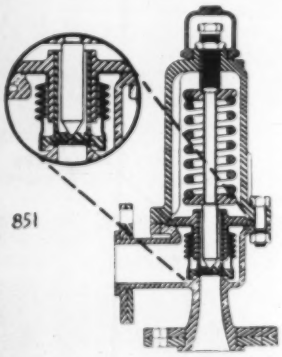
Stainless Chemical Meter

New line of stainless steel chemical meters for volumetric measurement of corrosive liquids are available in capacity range from 3 to 160 gpm. Units are available in two models, 1 in. DV and 2 in. GV for measurement of such corrosive products as caustic soda, most acids, fruit juices, liquid soap, molten sulphur, vinegar and similar liquids when metered free from air under 100 deg. F. Meters have working parts of type 316 stainless steel. Measuring piston is made of hard carbon or other materials as required. Outer castings are of 316 stainless steel, cast iron, cast bronze, or high-pressure cast carbon steel.—*Buffalo Meter Co., 2917 Main St., Buffalo, N. Y.*

Mention No. 234 when filling out card

Safety Valves With Bellows Seal Feature

New "FarriSeal Bellows" is said to be a new type of safety valve construction that completely isolates lading



fluid from valve spring chamber and guide surfaces. It completely seals spring, guides, adjusting screws, etc., from vapor or fluid in body of valve. Maker claims that guide cannot become fouled under any conditions, and that corrosion is minimized.—*Farris Engineering Corporation, 552 Commercial Avenue, Palisades Park, N. J.*

Mention No. 235 when filling out card

Oil-well Drilling Controller

New automatic control system, which provides exact weight for a drill bit as it penetrates oil-bearing formations thousands of feet below earth's surface, was developed cooperatively by companies in oil and refining industries, drilling equipment makers and industrial instrument engineers. System makes use of a strain gage assembly, a Brown electronic potentiometer which operates as a weight indicator on the drilling bit, and a pneumatic brake which maintains desired weight. Brakes feed drilling line at a rate which assures

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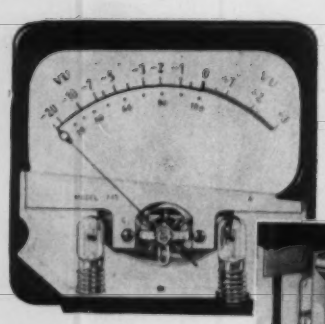

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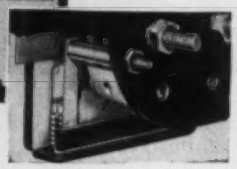

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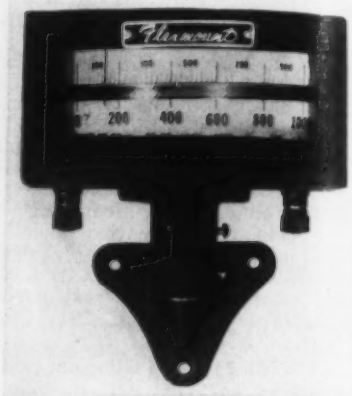
a constant and predetermined weight on bit through all types of sub-surface formations. — *Brown Instrument Co., Wayne and Roberts Aves., Philadelphia 44, Penna.*

Mention No. 236 when filling out card

Adjustable-mounting Pyrometer

New "Flexmount" pyrometer is unique in that it is adaptable for flush, surface or for swivel mounting for ease of installation and readability of scale

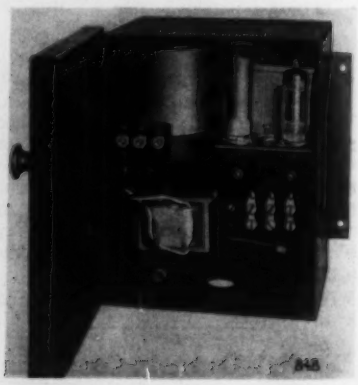


from any direction in semi-circle. Case moves through 180 deg. arc. Mirrored scale is 3.75 in. long with large numerals. High-resistance movement enables slight changes in external resistance of thermocouple lead wire without recalibration. Cold junction compensates automatically — *Pyramid Instrument Co., 117 Lafayette St., New York 13, N. Y.*

Mention No. 237 when filling out card

Electropneumatic Transducer

New "Microsen Pneumatic Transmitter" produces air-pressure output linearly proportional to d-c. input, serves as a transmitter for remote indication or recording; also for automatic-control operations. It measures



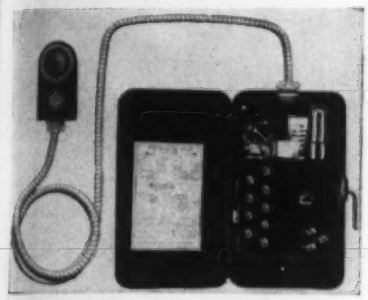
resistance, millivolts, microamperes as required for temperature, strain, speed, radiation, vacuum, humidity, etc. Pneumatic output is especially applicable in process control or where, for reasons of hazard or availability of equipment, pneumatic operation is desirable. Instrument is designed for 110- or 220-volt a.c. and 18-22-psi. supplies. Operation is not affected by variations in line voltage or supply pressure. Sensitive electromechanical balance is said to assure accuracy and stability. Combination elec-

tronic and pneumatic amplifier gives fast response: cross-range pressure changes of 3 seconds with moderate line capacity. Measuring element will detect and relay as pressure changes signals of an order less than 0.1 percent of calibrated range. Full-range sensitivity is 50 microamperes over an input resistance of 150 ohms. For use with thermocouples, device may be calibrated in temperature degrees and a reference junction provided when specified. Overall dimensions, 7 in. wide, 8 in. high, 4.5 deep. Weather-proof and explosion-proof housings available.—*Manning, Maxwell & Moore, Inc., Bridgeport 2, Conn.*

Mention No. 238 when filling out card

Photoelectric Controller

New "Type 20DJ1" photoelectric controller provides automatic control for such industrial applications as counting, conveyor control, short-range sig-

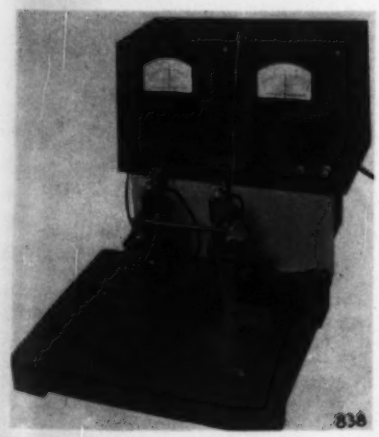


nal systems, etc. Phototube furnished integral or in separate housing. Instrument has sensitivity adjustment and operating range of 10 ft. Withstands high temperatures and humidity. Capacitors are hermetically-sealed and oil-filled; resistors are high-wattage type. Relay operates in 0.05 sec.—*Photoswitch, Inc., 77 Broadway, Cambridge 42, Mass.*

Mention No. 239 when filling out card

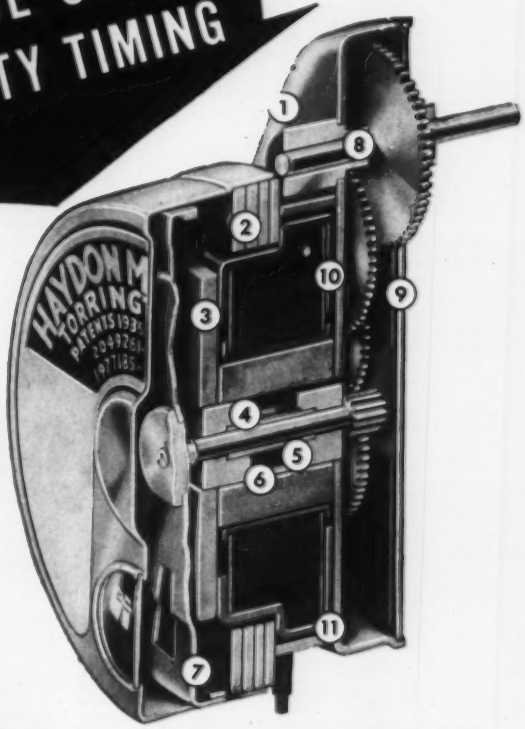
Duplex Electrical Micrometer

New "Two Channel Inspection Gage" for rapid simultaneous inspection of two diameters, has induction type measuring heads operating without friction and provided with 0.025-in. range of fine adjustment for ease in setups to



various sizes and fast correction for wear. Each head is independently adjustable. Zero-setting is done to mas-

THE INSIDE STORY ON QUALITY TIMING



HAYDON shows the way

This cross section of a Haydon timing motor illustrates a few of the exclusive, patented features that make Haydon synchronous motors and timers the most accurate and dependable in the field.

1. *Compact, sealed gear housing.*
2. *Shading coil construction gives high starting torque.*
3. *Field structure gives balanced torque characteristics.*
4. *Porous bronze graphite bearings filter lubricant to bearing surfaces.*
5. *Shaft housing seals lubricant away from motor shaft — prevents pumping.*
6. *Sealed reservoir for motor shaft lubrication.*
7. *Uniform reluctance ring rotor for uniform torque characteristics, rigidly held by spunover support.*
8. *Double bronze bearing on output shaft.*
9. *Lubricant carried by capillary attraction to each gear assembly individually, irrespective of mounting position of unit.*
10. *Protection against voltage surges with fold of insulation.*
11. *Projection-welded field assures accurate air gap and rugged construction.*

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ALFAX ELECTROSENSITIVE PAPER—marks directly by electric impulse. Density varies directly with intensity of signal so recordings can be made self-calibrating by introducing standard signals of different intensities.

ALFAX ELECTROSENSITIVE PAPER—in helix type recorder will record signal the instant it occurs—without overshooting,—no need for compensation or damping. IT IS INERTIA FREE.

ALFAX ELECTROSENSITIVE PAPER is extremely sensitive, so that the paper can be fed slowly, yet extremely rapid variations will be recorded in the helix stroke with no difficulty at writing speeds 800" or more per second.

ALFAX ELECTROSENSITIVE PAPER is ideal for recording a group of related signals without the problems of multiple pens and their maintenance. Recordings differentiate the transient or stray signals from the true signals. Sudden signals of unusual amplitude cannot damage the recorder nor result in false readings as in D'Arsonval movements and pen type movements.

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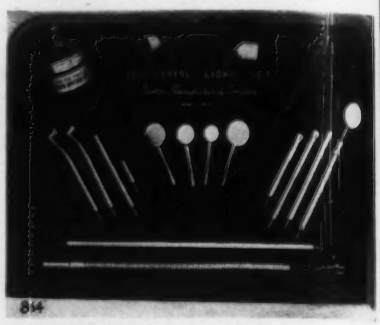
ters. In many cases, heads can be applied to existing stands with few changes; or stands can be supplied. Scales are linear, can be supplied to read to ten millionths of an inch. Amplifier operates on 110-volt 60-cycle supply and is voltage-regulated from 95 to 125 volts.—*Graham-Mintel Instrument Co., 2443 Prospect Ave., Cleveland 15, Ohio.*

Mention No. 240 when filling out card

Miniature Spotlight

New "Micro-Lite" set, similar to that used by dentists, has industrial applications in lighting small spots not readily visible—behind panels, around corners, in small openings. Set includes transformer, fittings, straight lamp and mirror. Light is hooded within 0.25 in. metal tube and extensions are available for lengthening light probe to 30 in. or more. Contra-angle lights are available as accessories.—*Burton Mfg. Co., 3855 N. Lincoln Ave., Chicago 13, Ill.*



Mention No. 241 when filling out card

Aircraft Altimeter

New "Type 160" altimeter provides pilots for first time with semi-direct reading instrument which is said to be much simpler and safer than present three-pointer type. Dial appears somewhat like automobile mileage counter, having one pointer and two-digit counter. Altitudes are shown on counter in thousands of feet and in 50-foot intervals by pointer. Pilot reads counter (e.g. "16" for 16,000 feet) and adds reading from pointer (e.g. 150 feet, making total of 16,150 feet). Engineering difficulties in perfecting new instrument are said to have numbered 160, thereby giving instrument its name. Dial is graduated at 50-foot intervals to 1,000 and will be furnished later for commercial use with 20-foot graduations. Each pointer revolution turns up

ne figure on counter which has all-ewel movement and incorporates de-ign that deduces torque for driving ointer by factor of 20. Actuating dia-hragm power has been increased eight-old. Instrument also embodies new type emperature compensator for accurate eadings over range of minus 60 to plus 60 deg. F. Altimeter has counterbal-nced parts to eliminate errors due to igh gravity loads at jet speeds.—*Kollsman Instrument Div., Square D Co.*, 180 *45th Ave., Elmhurst, N. Y.*

Mention No. 242 when filling out card

Pump for Instrument-controlled Process

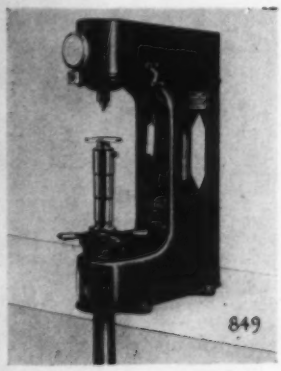
New "Model H" centrifugal pump is aid to be a highly efficient slow-speed (1,750 rpm.) pump for use where mod-

erate pressure and volume are required. Pump has shut-off pressure of 19 psi., 10 gpm. at 15 psi., and in excess of 20 gpm. at free flow. Furnished in bronze or aluminum with 0.16 to 0.33 hp. motor. Inlet is 0.5 in. NPT female and outlet is 0.375 NPT male.—*Eastern Industries, 295 Elm St., New Haven 6, Conn.*

Mention No. 243 when filling out card

Hardness Tester

New "Hardness Tester Model C-8A, C-12A, and C-16A" is a "Rockwell" hardness tester said to offer "an ease



and simplicity of servicing never before available in this field." Spindle housing and beam assembly may be replaced by owner without special skill or special tools, thereby reconditioning his instruments in his own plant. Other advan-

Standard for Industry

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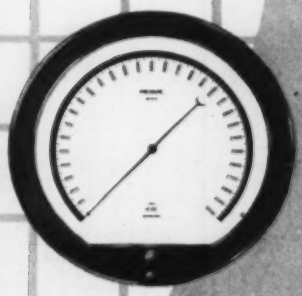
dial scale is always concentric with the pointer travel



HEISE GAUGES

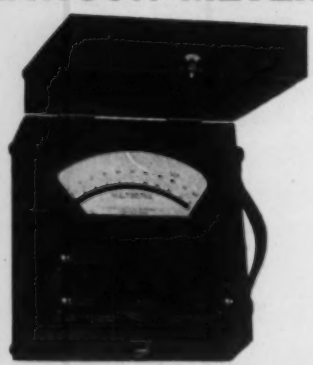
STANDARD OF THE WORLD

The scales of Heise Bourdon tube pressure gauges are absolutely concentric with the pointer rotation. Errors due to misalignment in mounting or cutting the scales are avoided since the scales are cut from their centers, and are mounted at the centers on a hollow spindle through which the pointer rotates.

Three sizes: 8½ in., 12 in., and 16 in., in ranges from 0-15 to 0-10,000 psi. Prices from $151.60 to $211.20. Write for catalog.

Heise Bourdon Tube Company, Inc.
Newtown, Connecticut

RAWSON METERS



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AC and DC types, high accuracy, multiple ranges.
2 microamperes to 1 ampere DC.
2 milliamperes to 3 amperes AC.

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Ranges 150-v. to 35,000-v AC or DC.
Resistance exceeds million megohms.
Can measure static electricity.

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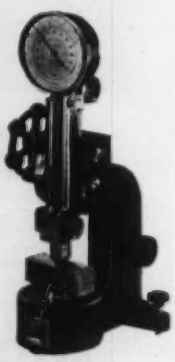

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The Shore Instrument & Mfg. Co., Inc.

9025 Van Wyck Ave., Jamaica 2, N. Y.

tages claimed include a frictionless spindle, more positive tripping and exceptionally light weight; aluminum body weighs 65 to 85 pounds less than steel or cast iron.—*Clark Instrument Inc.*, 10200 *Ford Road, Dearborn, Mich.*

Mention No. 244 when filling out card

Welding Control Combination

New "Model 160-53BA1" dwarf control combination for welding includes timer and high-speed magnetic contactor in shock mounting, ready to install. Unit is 17x14.375x8 in. deep. Contactor does not require dressing, cleaning or filing and can be had in 100 or 150 amp. sizes. Timer is single-stage type with continuous adjustment from 3-120 cycles. Operates from 110, 230, 460 volts a.c.—*Weltronic Co.*, 19464 *West Eight Mile Road, Detroit* 19, *Mich.*

Mention No. 245 when filling out card

High-speed Solenoid-controlled Air-powered Air Valve

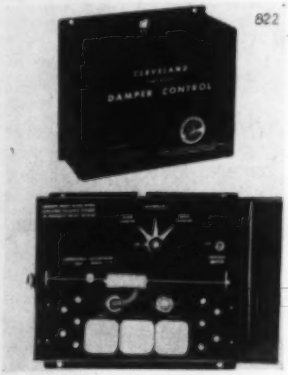
New solenoid-controlled air control valve is operated by the air it controls. A light-weight piston floating in a cylinder engages and shifts a four-way shear-flow air valve. Caps enclosing each end of the cylinder hold small air-cooled 8-volt solenoids whose plungers, operating with only 0.031-in. movement, release full pressure of air supply line to drive piston and thus shift four-way valve in desired direction. Valve will operate on 5 to 150 psi. air-line pressure. New valve is so fast in its movements that test counters could not record its speed after it passed 2200 movements per minute. Heat generated even after hours of test, was scarcely noticeable to the touch. Light-weight piston is cushioned at both ends, operates without shock or

noise. Valve will operate submerged, or covered with coolant, chips or dust. Water or oil in air line will not affect its operation. Switches for operating may be placed either in 8-volt secondary circuit or in 110-volt primary circuit. New valve is available in 0.25-in. and 0.375-in. port sizes; comes complete with transformer.—*The Bellows Co., 228 W. Market St., Akron, Ohio.*

Mention No. 246 when filling out card

Time-delay Damper Control

New electric remote damper control contains in one case all elements for safe, automatic control of stack draft.

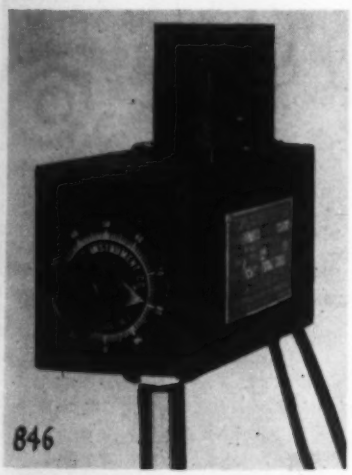


Unit is said to save fuel, protect boiler plant equipment, reduce smoke, increase safety. Has differential adjustment for setting at any desired sensitivity, selector switch for manual control, and emergency cut-out switch for instantaneous return to manual control. Control is adaptable to oil, stoker of gas-fired boilers.—*Cleveland Fuel Equipment Co., 1836 Euclid Ave., Cleveland 15, Ohio.*

Mention No. 247 when filling out card

Automatic Temperature Controller

New "Model D" temperature controller combines maker's high-sensitivity solid-expansion type primary element and "Atcotran" displacement-sensitive electrical transmission (see our Sept. 1948 issue, page 806). This is said to result in "extreme sensitivity and accuracy. In a demonstration, a good-size valve was moved 90 degrees



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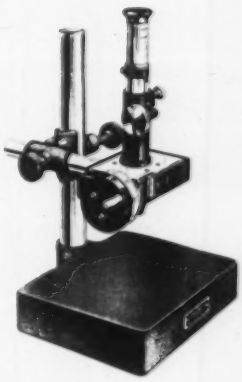
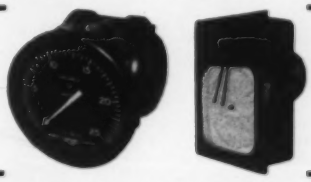


REQUEST BULLETIN 161-48

THE GAERTNER SCIENTIFIC CORP.
1211 Wrightwood Ave. : Chicago 14 : U.S.A.

NEW BARTON *FLOW METERS*

MODEL 200 DIFFERENTIAL PRESSURE INDICATOR



MODEL 202 DIFFERENTIAL PRESSURE RECORDER

For the first time, long desired operating characteristics of the actuating element in flow meters has been achieved by Barton Instrument Company.

Stainless Steel Rupture-Proof Bellows • Torque Tube Drive • Self Venting or Draining Actuating Unit • Removable Pressure Chambers • Differential Range: 0-20 W.C. to 0-300 W.C.

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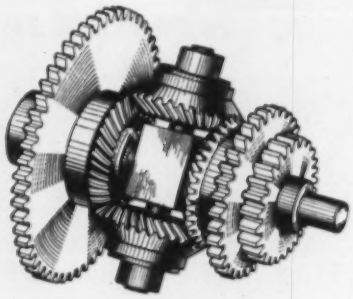
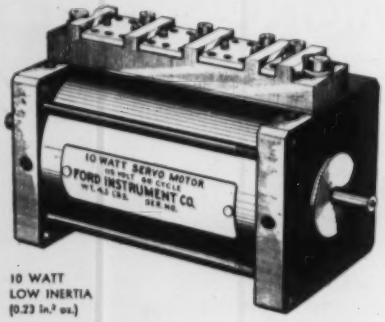
DIFFERENTIALS

3/16" 1/4" 5/16"

Precision Plus!





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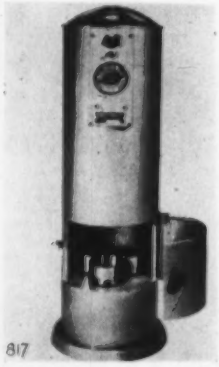
INTEGRATORS ESTABLISHED 1915 TELESYNS

by the temperature change resulting from a hand grasping the brass tube." New instrument is recommended for extremely sensitive control of gas valves, dampers, etc.—*Burling Instrument Co., 253 Springfield Avenue, Newark 1, N. J.*

Mention No. 248 when filling out card

Laboratory Oven

New laboratory drying oven is said to require half the time otherwise needed to remove moisture or volatile

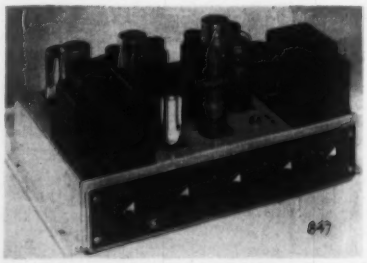


materials from samples. Unit is 29 in. high, has heating chamber 5 in. high and of 8 in. diameter. Filtered air, heated electrically and driven by electric fan, passes over and around sample then through exhaust. Temperature thermostatically controlled between 150 to 350 deg. F. Draws 2800 watts on 110 or 230 volts.—*Harry W. Dietert Co., 9330 Rosetown Ave., Detroit 4, Mich.*

Mention No. 249 when filling out card

Dynamic Noise Suppressor Amplifier

New "210-A Laboratory Amplifier with Dynamic Noise Suppressor" embodies improvements: oversize output



transformer said to provide "remarkable freedom from distortion" and reduce hum level to 86 db below maximum power output under normal operating conditions (actual hum power level 0.05 microwatt). New anodized aluminum chassis eliminates tarnishing, withstands rubbing and chafing of constant use.—*Hermon Hosmer Scott, Inc., 385 Putnam Ave., Cambridge, Mass.*

Mention No. 250 when filling out card

Electron-multiplier Photometer

New electron-multiplier photometer, for measuring extremely low light intensities, utilizes photomultiplier tubes which obviate need for additional amplifiers. Applicability is widened by choice of photomultiplier having opti-

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MERCURY COLUMN GAUGES

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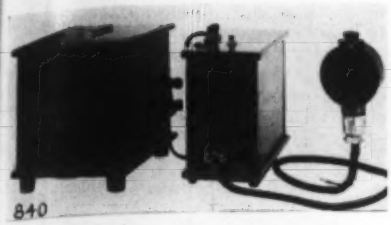
TESTING INSTRUMENT CO. INC.
48 Van Sinderen Ave., Brooklyn, N. Y.

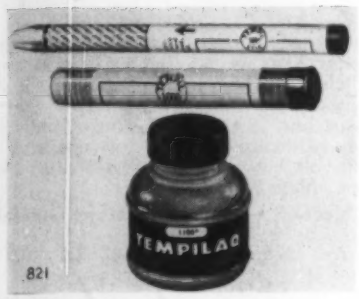


mum characteristics in ultraviolet or visible. Photometer comprises: (1) detector, (2) power supply and controls, (3) galvanometer. This arrangement makes it convenient to use directly or attach photometer to various instruments. Among features: Selective wide range of sensitivity; linear response; dark-current balance control; constant voltage; stable battery power supply; interchangeable photomultiplier tubes. —*Farrand Optical Co., Inc.*, 4401 *Bronx Blvd., New York* 66, *N. Y.*

Mention No. 251 when filling out card

Temperature Indicators

New temperature ratings of maker's "Tempilstiks" (crayons), "Tempilaq" (liquid) and "Tempil" pellets provide

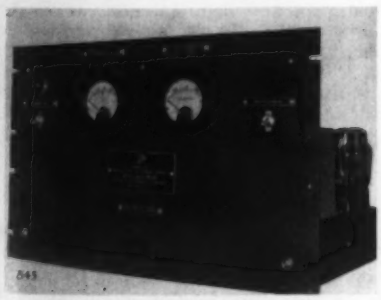


fuller range of these temperature-indicating products. All three products are now available in 12.5-degree intervals from 113 deg. to 400 deg. F. From 400 to 1600 deg. F. "Tempilstiks" and "Tempilaq" are available in 50-degree increments while "Tempil" pellets can be had up to 1700 deg. F.—*Tempil Corp.*, 132 *West* 22*nd St., New York* 11, *N. Y.*

Mention No. 252 when filling out card

High-precision D-c. Power Supply

New "Model 252 Super-regulated DC Power Supply" has 115-volts 60-cycle input of 400 watts; output adjustable from 260 to 300 volts d.c., negative grounded. With load changes from 400 to 600 milliamperes, output voltage



change at any setting is less than 0.05 percent, varying between individual units from 0.015 percent to 0.04 percent. Equal stability exists with respect to

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Your equipment goes right on producing *should* replacement of a Senior Midget Industrial Thermometer be necessary. The unique design of this proved instrument also eliminates the costly and time consuming procedure of returning damaged themometers to the factory for repair. With the YEL O BAK Senior Midget your own maintenance man does the job quickly, right on the spot.

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Bulb Chamber, which is removable with Armor for easy access to damaged stem and removal of broken section.

Separable socket which remains as seal in equipment, permitting its uninterrupted operation and production.

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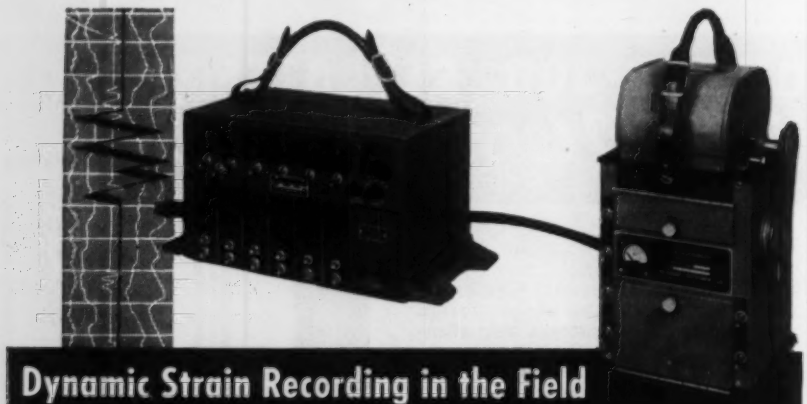

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The TYPE MRC-12 6-ELEMENT SELF-POWERED STRAIN GAGE CONTROL UNIT, and the TYPE S15-A 6-ELEMENT SELF-POWERED RECORDING OSCILLOGRAPH together make up a complete dynamic strain measuring laboratory which you can carry with you for field use ANYWHERE where electrical power is not available.

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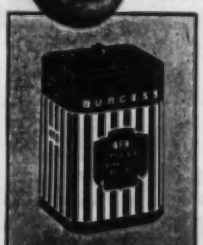

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minor line voltage changes. N[illegible]e level is less than 0.001 percent. New [illegible]nit has applications wherever extrem[illegible]y good regulation and stability are [illegible]uired: computer circuits, television [illegible]plifier circuits, servomechanism direc[illegible]rs, etc. —*Beta Electronics Compa[illegible], 1762 Third Avenue, New York* 29, [illegible] Y.

Mention No. 253 when filling o[illegible] card

Field Strength Meter

New "Model FSM-1" field strength meter permits measurements of actual picture signal strength for television

receivers, in the range 50-50,000 microvolts. Also useful in checking antenna efficiency. Complete television set not necessary when making test. Instrument has 18-channel selector, individually-calibrated meter and operates on 120-volt 60-cycle supply—*Transvision, Inc., New Rochelle, N. Y.*

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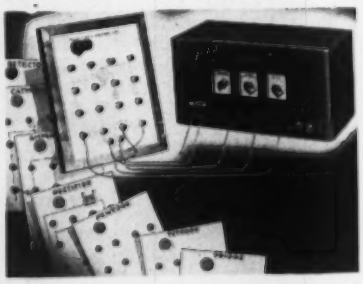
Circuit Panel Kit

New electrical circuit panel kit for student and laboratory use now has 27 keyed circuit diagrams, four new ones

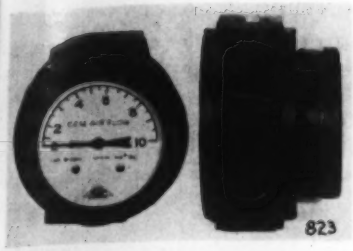


being for superheterodyne radio circuits. When wired to multiple power supply, instrument can be used to investigate and demonstrate various circuits as well as characteristics of vacuum or gas-filled tubes. Furnished with two "B" supplies, variable "C" supply and heater supply. — *Kepco Labs., Flushing, N. Y.*

Mention No. 255 when filling out card

Indicating Flowmeter

New indicating flowmeter is claimed to have quick response and high accuracy, and can be obtained in models for horizontal or vertical mounting. Dial is 4.25 in. in diameter, scale is 6.25 in. long, and instrument is of movable-vane type with geared pointer. Removable front and back plates. Light-weight movable element follows air flow fluct-

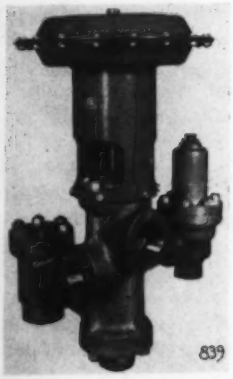


uations closely and vane is weighted at tip to provide strong zero torque Unique feature is flexible metal liner in flow chamber with controllable curvature to determine scale law. Furnished with standard tapped holes up to 1.25 in.—*Seico, Inc.*, 10210 *South Hoyne Ave., Chicago* 43, *Ill.*

Mention No. 256 when filling out card

Hydraulic Operating Valve

New two-pressure operating valve for hydraulic presses, etc., is an assembly of three independent valves



each of which may be installed in most suitable position for simplified piping; or unit can be installed as an assembly. Low pressure (100 to 700 psi) is admitted to main or three-way valve through hydraulic angle check valve; high pressure is introduced through either automatic inlet or through a diaphragm valve.—*The Valv-Trol Co.*, 167 *Hill St., Akron* 8, *Ohio.*

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ENGINEERING AND SALES REPRESENTATIVE

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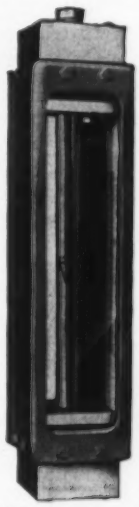

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TEMPERATURE CONTROL *Continued from page 136*

sub-tangent AB. The latter will have to be expressed seconds as it corresponds to a length of time; indeed, if we compare Formulae (8) and (9), we will see that:

$$AB = T/\log(\theta_1 - \theta_2)$$

It must be noted that the value of the relative variation v of the heated fluid flow can be either positive or negative; indeed, when the new flow of this fluid is smaller than the former, we have:

$$q_2 < q_1 \text{ and } v = [(q_2 - q_1)/q_1] < 0$$

It is obvious that, in any case, the value of v cannot be smaller than -1, which is a limiting value corresponding to the case when the flow of heated fluid is suddenly cut off. The term $(v+1)$ which we find in various formulae is, therefore, always positive.

The method described above makes it possible in this way to determine, by means of comparatively simple real tests, the value of the entirely fictitious heat inertia of the heating unit. We shall outline now the part borne by this inertia in the case of heating units not provided with automatic temperature controllers. Let us consider several heating units having different fictitious masses and let us suppose that they are brought to the same temperature θ_1 and fed with cold fluid having the same temperature θ_0.

Equation (3) shows that, if we subject these heating units to the same relative variation v of the heated fluid flow, the temperature of stabilization θ_2 will also be the same for all these heating units, in spite of their very different fictitious masses, as the value of the fictitious mass does not interfere in formula (3) and as the value of θ_2 is therefore, independent of the latter.

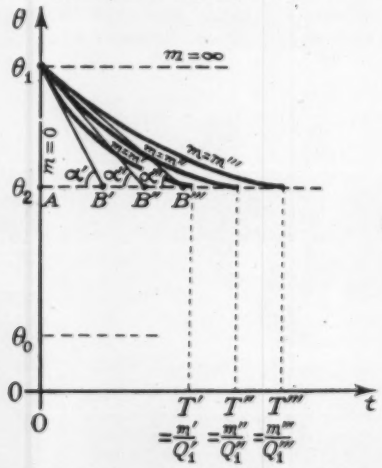

Fig. 2

On the other hand, Equation (7) shows us that, in the same case, the time required for stabilizing the temperature existing inside these various heating units will be each time proportional to the various quotients m/Q_1, m'/Q'_1, m''/Q''_1, etc.

If the flows of heated fluid drawn from these various heating units are identical, the time required for stabilizing the temperature inside these various heating units will be proportional to their respective fictitious masses. This is illustrated in Fig. 2.

Thus, for a fictitious mass equal to 0, the curve $\theta(t)$ will be a vertical straight line (immediate variation of temperature) while, for an infinite fictitious mass, this curve will have the form of a horizontal straight line $\theta = \theta_1$ and no variation of temperature will be possible at all. The fictitious mass of a heating unit has, therefore, no influence on the amplitude of temperature fluctuations inside the unit, but has an influence on the time required for their stabilization.

We will now study the various systems of automatic temperature control, on the basis of the following classification which takes into consideration, not their external features (such as electricity, compressed air, etc., or such as vapor tension, thermocouple, electric resistance, etc.), but the form of the general law governing each of these systems; we will thus have the following classification:

1. Discontinuous Automatic-control Systems:

(a) On-off or Single, maximum, Step Control.

(b) High-low or Two, maximum and minimum, Step Control.

(c) Successive Multiple-step Control (an extension of the Two-step Control).

2. Continuous Automatic-control Systems:

(a) Floating control with Automatic Reset action alone (as a function of time elapsed alone).

(b) Positioning Control with Throttling action alone (as a function of temperature alone).

(c) Positioning Control with both Throttling and Automatic Reset actions (as a function of both time elapsed and temperature).

DISCONTINUOUS CONTROL SYSTEMS

We will start by a study of the Discontinuous Control systems. All of these systems have a common feature: the absence of balance at any moment, even when the flow of the heated fluid drawn from the heating unit is not subjected to any variation; indeed, with these automatic control systems, the heat input to the heating unit is either much higher or much lower than that required for maintaining the heated fluid at a given temperature, so that the temperature inside the heating unit increases or decreases and, generally speaking, cycles continuously between given limits.

This rule is a general one, but we can cite among these discontinuous control systems, the *"on-off" control*, under which the heat input to the heating unit is periodically equal either to a definite value—which, as a rule, is higher than the heat input required to maintain the heated fluid at temperatures comprised within the chosen limits of control—or to 0, or the *"high-low" control*, under which this heat input is periodically equal either to a maximum, as above, or to a given minimum, without ever decreasing down to 0; we can cite, finally, the *"successive multiple-step" control*, under which the temperature inside the heating unit, instead of cycling between two given limits, will cycle between several pairs of limits, one pair of limit temperatures being automatically substituted for another as soon as the flow of the heated fluid drawn from the heating unit is subjected to somewhat large variations.

The on-off control is a particular instance of the high-low control: the instance in which the minimum heat input is equal to 0; on the other hand, the successive multiple-step control is an extension of the high-low control to several pairs of limit temperatures and to several values of the heat input to the heating unit instead of two limit temperatures and of two (maximum and minimum) values of this heat input.

We shall therefore determine, in order to avoid unnecessary calculations, the various equations and formulae in the case of the "high-low" control; and then adapt the results to the two other methods of discontinuous control.

The general expression for equilibrium of heat flow in this case is:

$$q(\theta-\theta_0)dt = -md\theta+Qdt$$

For the present, consider q constant. Now Q has one of two constant values, Q_{max} and Q_{min}. Consider first the case where θ has just reached its maximum value θ_1 and Q is equal to Q_{min}. We then have:

$$-m\frac{d\theta}{dt} = q(\theta-\theta_0)-Q_{min} \qquad \ldots (10)$$

Integrating and putting in the condition that $\theta=\theta_1$ when $t=0$, we have:

$$t = -\frac{m}{q}\log\frac{q(\theta-\theta_0)-Q_{min}}{q(\theta_1-\theta_0)-Q_{min}} \qquad \ldots (11)$$

and

$$\theta = \theta_1-(\theta_1-\theta_0-\frac{Q_{min}}{q})\left\{1-\exp[-\frac{Q_{min}}{q}t]\right\} \qquad \ldots (12)$$

which is the equation of the decreasing branch of the curve in Fig. 3.

This curve tends to an asymptotic limit $\theta=\theta_2$; if we make in equation (12) $t=\infty$, we shall find:

$$\theta_2 = \theta_0+Q_{min}/q \qquad \ldots (13)$$

from whence: $Q_{min}=q(\theta_2-\theta_0)$

Now the control is set at some lower limit θ_2 which is greater

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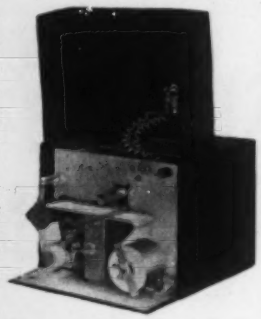

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than θ_2. The time t_1 for the temperature to fall from θ ... θ_2 can be obtained from Eq. (11) and is:

$$t_1 = \frac{m}{q} \log \frac{q(\theta_1-\theta_0)-Q_{min}}{q(\theta_2-\theta_0)-Q_{min}} \quad \ldots (14)$$

At the moment $t=t_1$ when the curve θ (t) reaches ... lower limit of control θ_2, the minimum heat input per unit of ... Q_{min} is automatically replaced by the maximum heat input p... unit of time Q_{max}, and the temperature inside the heating unit ...gins to

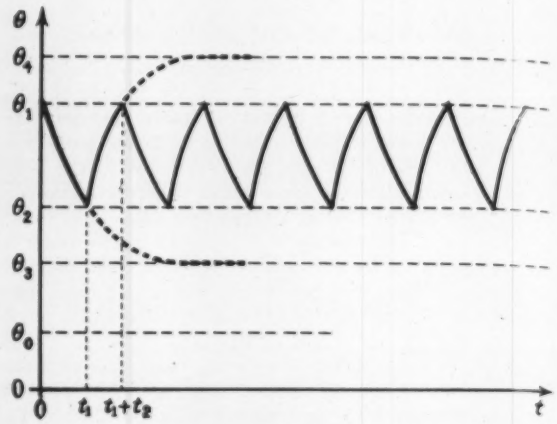

Fig. 3

increase. The temperature follows then, between θ_2 and θ_1, the increasing branch of the periodic curve $\theta(t)$ and, when the higher limit of control θ_1, is again reached, the system cycles indefinitely (see Fig. 3).

The fundamental equation (1) applying, as it has been outlined to the instance of increase of temperature as well as to that of decrease of temperature, it is easy to obtain the equations of the increasing branch of the curve $\theta(t)$ from those of its decreasing branch by replacing $Q_{min.}$ by $Q_{max.}$ and θ_1 by θ_2; we obtain in this way:

$$-m\, d\theta/dt = q(\theta-\theta_0)-Q_{max} \quad \ldots (15)$$

$$t = -m/q \log \frac{q(\theta-\theta_0)-Q_{max}}{q(\theta_2-\theta_0)-Q_{max}} = -m/q \log \frac{Q_{max}-q(\theta-\theta_0)}{Q_{max}-q(\theta_2-\theta_0)} \quad \ldots (16)$$

$$\text{and } \theta = \theta_2-(\theta_2-\theta_0-Q_{max}/q)[1-\exp(-q/mt)] = \theta_2+[Q_{max}/q-(\theta_2-\theta_0)][1-\exp(-q/mt)] \quad \ldots (17)$$

The increasing branch of the curve $\theta(t)$ will tend to an asymptotic limit $\theta=\theta_4$, such that:

$$\theta_4 = \theta_0+Q_{max}/q \quad \ldots (18)$$

from whence: $Q_{max}=q(\theta_4-\theta_0)$

The upper temperature θ_1, at which the control is set, is less than θ_4; and the time t_2 required to heat the tank from θ_2 to θ_1 is:

$$t_2 = \frac{m}{q} \log \frac{Q_{max}-q(\theta_2-\theta_0)}{Q_{max}-q(\theta_1-\theta_0)} \quad \ldots (19)$$

It will be noted that the formulae obtained for the decreasing branch of the temperature curve in Fig. 3 as well as for its increasing branch correspond to the particular case in which the heated fluid is water. In order to give them a general meaning, it is necessary to incorporate in these formulae the specific heat c and the density α of the considered heated fluid by replacing the value of q by the appropriate value of $c\alpha q$.

If we study formulae (14) and (19) which give respectively the time interval t_1 of operation with the minimum heat input Q_{min} and the time interval t_2 of operation with the maximum heat input Q_{max}, we shall see that t_1 and t_2 are expressed by a logarithmic term—different in each case—multiplied by the same term m/q. We can conclude from this, that, first of all, the length of each cycle of temperature variations is proportional to the fictitious mass of the heating unit, this fictitious mass bearing, therefore, under discontinuous automatic control, a part exactly

similar to that borne in heating units having no temperature controller at all.

If we then examine the logarithmic terms of formulae (14) and (19), we shall see that these terms are equal to 0 when $\theta_1 = \theta_2$ and that they increase with the difference between the limit temperatures of control θ_1 and θ_2, i.e., with the decrease of the sensitivity of the considered temperature controller.

We can therefore say that the less sensitive is a given temperature controller, the less frequent will be the temperature variations created by its intervention and the greater, consequently, will be the stability of the discontinuous control it insures.

We will study now the influence of variations of the heated fluid flow q on the operation of a discontinuous automatic control system; formulae (14) and (19) show that an increase of this flow results in a decrease of the length of temperature variation cycles: i.e., in an increase of the frequency of these variations and that, consequently, the decrease of this flow results in turn in a decrease of this frequency.

We have already seen that $Q_{max} > q(\theta_1 - \theta_0)$

from whence $q < \frac{Q_{max}}{\theta_1 - \theta_0}$

If the flow of heated fluid increases abnormally and reaches the limit $q = \frac{Q_{max}}{\theta_1 - \theta_0}$ we shall have: $q(\theta_1 - \theta_0) = Q_{max}$ and the logarithmic term of formula (19) will become infinite, from whence $t_2 = \infty$; the operation will thus, become continuous with the maximum heat input Q_{max} and the temperature shall be stabilized at $\theta = \theta_1$ or at $\theta < \theta_1$ (if q becomes greater than $\frac{Q_{max}}{\theta_1 - \theta_0}$).

We have seen, on the other hand, that $Q_{min} < q(\theta_2 - \theta_0)$

from whence $q > \frac{Q_{min}}{\theta_2 - \theta_0}$

If the flow of heated fluid decreases abnormally and reaches the limit $q = \frac{(Q_{min})}{\theta_2 - \theta_0}$ we shall have $q\ (\theta_2 - \theta_0) = Q_{min}$ and the logarithmic term of formula (14) will become infinite, from whence $t_1 = \infty$; the operation will, thus, become continuous with the minimum heat input Q_{min} and the temperature shall be stabilized at $\theta = \theta_2$ or at $\theta > \theta_2$ (if q becomes smaller than $\frac{Q_{min}}{\theta_2 - \theta_0}$).

The temperature controller acts, therefore, only when the variations of the heated fluid flow remain within the limits $\frac{Q_{max}}{\theta_1 - \theta_0}$ and $\frac{Q_{min}}{\theta_2 - \theta_0}$ $(\frac{Q_{max}}{\theta_1 - \theta_0} > q > \frac{Q_{min}}{\theta_2 - \theta_0})$; if the variations of the heated fluid flow extend beyond these limits, the heating unit operates continuously either with the maximum heat input or with the minimum heat input and the temperature remains within the limits θ_1 and θ_2, under the condition, however, that this flow shall not extend beyond new wider limits equal to $\frac{Q_{max}}{\theta_2 - \theta_0}$ and $\frac{Q_{min}}{\theta_1 - \theta_0}$ $(\frac{Q_{max}}{\theta_2 - \theta_0} > q > \frac{Q_{min}}{\theta_1 - \theta_0})$.

The limits we have mentioned are widened and insure thus the action of the controller and the maintenance of the temperature between two given values θ_1 and θ_2, for a larger number of values of the heated fluid flow by widening the interval between Q_{max} and Q_{min} and by narrowing that between θ_1 and θ_2.

Therefore, in a given heating unit in which it is impossible to alter its fictitious mass, the only means of insuring the best possible discontinuous automatic control consists in a choice of the respective values of Q_{max} and Q_{min} so that they would be sufficiently high and sufficiently low for the considered application and in a minimum interval between the limit temperatures of control θ_1 and θ_2 acceptable under the operating conditions of this heating

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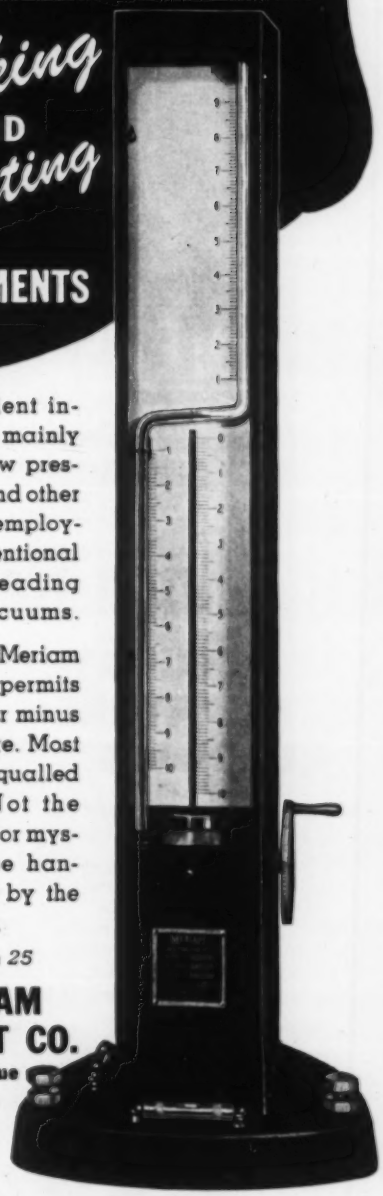

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unit; it is obvious that this last condition is bound by the inconveniences of an excessive sensitivity of the automatic controller and the resulting excessive frequency of temperature fluctuations.

In what concerns the first condition, it is never good to give Q_{max} an excessive value which would result in a relative decrease of the logarithmic term of formula (19), i.e., in a decrease of t_2 and in an excessive increase of the frequency of temperature variations; we can say as much for an excessive decrease of Q_{min} which would diminish the logarithmic term of formula (14) and, therefore, t_1—so that the condition of giving Q_{max} and Q_{min} their maximum and minimum values is bound by the caution of avoiding an excessive frequency of temperature variations.

In the instance of On-Off Control, it will be sufficient to make, in all preceding formulae, $Q_{min}=0$ in order to obtain the formulae corresponding to this kind of control; we will see, if we run over formula (13) that the theoretical asymptotic limit to which tends the decreasing branch of the curve $\theta(t)$ in Fig. 3 becomes in this case, equal to $\theta_2=\theta_0$.

The successive Multiple Step Control—which is an extension of the High-Low Control—allows a better accordance between the contradictory conditions of a sufficient sensitivity of the controller and of a sufficiently small frequency of temperature variations which we have just studied; this method of control insures, indeed, for a given interval between temperatures of control, several

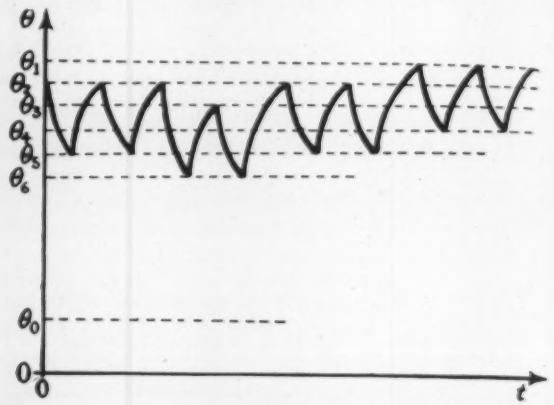

Fig. 4

values for Q_{max} and Q_{min} which are thus sufficiently close one to another in each case to avoid an excessive frequency of temperature variations.

In order to give a clearer understanding of this method of control, we shall call as before, θ_1 the higher limit of control, but shall call θ_6 its lower limit; we will assume, on the other hand, as an example—that instead of two steps of heat input per unit of time Q_{max} and Q_{min}, there will be four steps respectively equal to Q_1, Q_2, Q_3 and Q_4 and such that $Q_1<Q_2<Q_3<Q_4$.

We shall call, on the other hand (see Fig. 4) θ_2, θ_3, θ_4 and θ_5 temperatures comprised between θ_1 and θ_6 and such that the heat input Q_4 would be automatically replaced by a lower heat input Q_3 when the increasing temperature reaches θ_3, that Q_3 would be, in turn, replaced by Q_2 when this temperature reaches θ_2 and that, on the other hand, Q_1 would be replaced by a higher heat input Q_2 when the decreasing temperature reaches θ_4, whilst Q_3 would be, in turn, replaced by Q_3 when this temperature reaches θ_5.

Under these conditions, when the increasing temperature would reach θ_1, the heat input Q_2 would be replaced by Q_1 and, on the other hand, when the decreasing temperature would reach θ_6, the heat input Q_3 would be automatically replaced by Q_4.

If the heated fluid flow is between $\frac{(Q_2}{(\theta_2-\theta_0}$ and $\frac{Q_2)}{\theta_5-\theta_0)}$, the temperature will remain within the limits θ_2 and θ_3 between which it will cycle. If this flow becomes greater than $\frac{Q_3}{\theta_2-\theta_0}$, the temperature will decrease while remaining within the limits θ_2 and θ_5 and the heating unit will continuously operate

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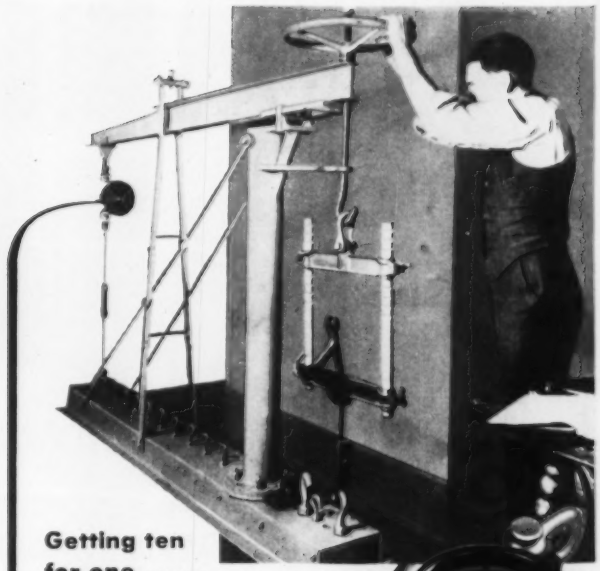

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ACCURATE control of temperature or pH is vital to modern heat treating or chemical processing, because only in this way can uniform quality be obtained under mass production conditions.

Potentiometers have made such control possible, and "the heart" of these instruments in most cases, for over 25 years, has been the Eplab Standard Cell. This cell is a "yardstick" for the translation of voltage to temperature. The first commercial cell of its type, constant research has made it "as standard as sterling".

When you buy potentiometers, specify Eplab Standard Cells.

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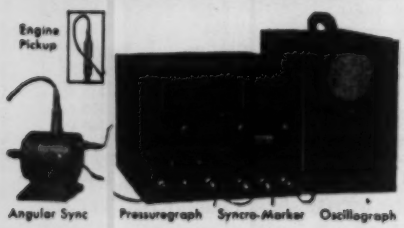
EPLAB Standard Cells For Potentiometric Instruments As Expressed in Sterling

New Tools You Should Have for **PRESSURE RESEARCH**

The Synchro-Marker

PRESSUREGRAPH



Here is your complete answer in instrumentation for checking pressure variations, both regular and instantaneous. Provides oscillograph pictures showing relation of pressures to engine shaft rotation (top dead center) or indications in degrees of rotation and also relates pressure to time (milliseconds).

Accurately measures pressure rise with time. Can be applied to hydraulic, gas, steam or pressure line measurement of static, dynamic or instantaneous pressures.

New detachable diaphragm permits measurement in any pressure range from vacuum to 14,000 p.s.i.

Now used in oil fields by many leading producers.

ITS LITERATURE

Write for your copy of "Pressure Indications in Engine Fuel Research" illustrating typical Pressuregraph applications and giving data on dynamic studies of pressure waves.

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with the heat input Q_3 until the moment when this flow will reach the new higher limit $(\frac{Q_3}{\theta_4-\theta_0})$. This last limit being over run, the heating unit will operate alternately with the maximum heat input Q_4 and the heat input Q_3 which will become from a maximum step a minimum step and the temperature will be maintained within the limits θ_3 and θ_4.

On the other hand, if the heated fluid flow becomes smaller than $\frac{Q_2}{\theta_3-\theta_0}$ the heating unit will no more operate alternately with heat inputs Q_3 and Q_2 but only with the minimum heat input Q_2 until the new minimum limit $(\frac{Q_2}{\theta_1-\theta_0})$ will be reached; at this moment, the temperature inside the heating unit will reach θ_1 and the latter will operate alternately with heat inputs Q_2—which will become a maximum—and Q_1, the temperature cycling between the limits θ_1 and θ_4.

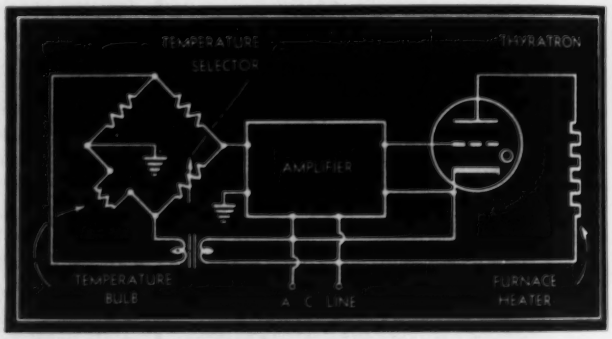
It is obvious that if the heated fluid flow becomes greater than $(\frac{Q_4}{\theta_4-\theta_0})$ the temperature will decrease below θ_4, just as this temperature will increase above θ_1 if this flow becomes smaller than $(\frac{Q_1}{\theta_1-\theta_0})$; nevertheless, the Successive Multiple Step Control has the advantage over the High-Low Control of enabling to give Q_4 and Q_1 respectively very high and very low values without creating thus an excessive frequency of temperature variations.

We shall continue this essay by the investigation of continuous automatic control systems. Before ending, we must outline the fact that in order to simplify calculations we have not and will not take into consideration the inertia of the controllers themselves, which is relatively small and which could be obtained from comparative tests effected without and with the considered controller.

(To be continued)

MACDONALD

PROPORTIONING TEMPERATURE CONTROLLER



Range: Room temperature to 1000° F (special or higher ranges on request)

Controls Temperature Within: 0.1° F

Output Power (*available for furnace winding*):

	Type A	Type 18B
110 volt operation	225 watts	825 watts
220 volt operation	550 watts	1650 watts

Prices: f.o.b. Cambridge, Mass. Type A — $290.00
Type 18B — $375.00
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This modern

SOUND-LEVEL METER

GIVES UNEQUALLED SPEED, ACCURACY, and CONVENIENCE

SPECIFICATIONS

- ★ **Accuracy: meets ASA standards.**
- ★ **Range: 34 to 140 db above ASA reference level. All standard ASA curves for weighting are provided: flat, 70db, and 40db.**
- ★ **Microphone: humidity-sealed crystal, diaphragm-type.**
- ★ **Meter: two-speed type provides either standard ASA ballistics or heavy damping.**
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- ★ **Size: 11¾ inches long — 2½ inches in diameter.**
- ★ **Weight: 2 lbs., 7 oz.**

The H. H. Scott sound-level meter is the only truly modern sound-level meter now available. Self contained, the instrument is unsurpassed for speed, accuracy, and convenience. Held and operated in one hand, it is merely pointed at the noise source and an accurate reading taken from the meter.

Provision is made for using the microphone on an extension cable or for using other microphones, vibration pickups, etc.

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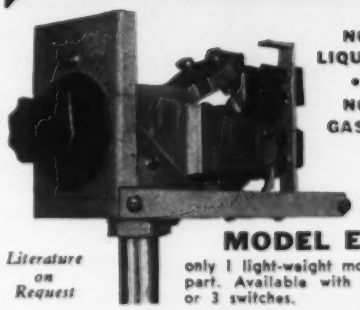

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Literature on Request

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only 1 light-weight moving part. Available with 1, 2 or 3 switches.

As a 3 switch model, Burling Model E is recommended for use (a) where load is divided into 3 parts, (b) where 1 switch is used for controlling, one as a high limit, one as a low limit, (c) to give definite stops or position to a 3 or 4 position diaphragm motor, (d) to give 3 speed control of variable speed motor.

Accurate, rugged, dependable. Corrosion and heat resisting tube. Dial pointer for easy setting. Locking screw locks temperature setting. Increased adjustable range to 700-1000°. Dimensions: 7¼" x 2⅝" x 3½". Vapor tight base and cover with gasket available at slight extra charge.

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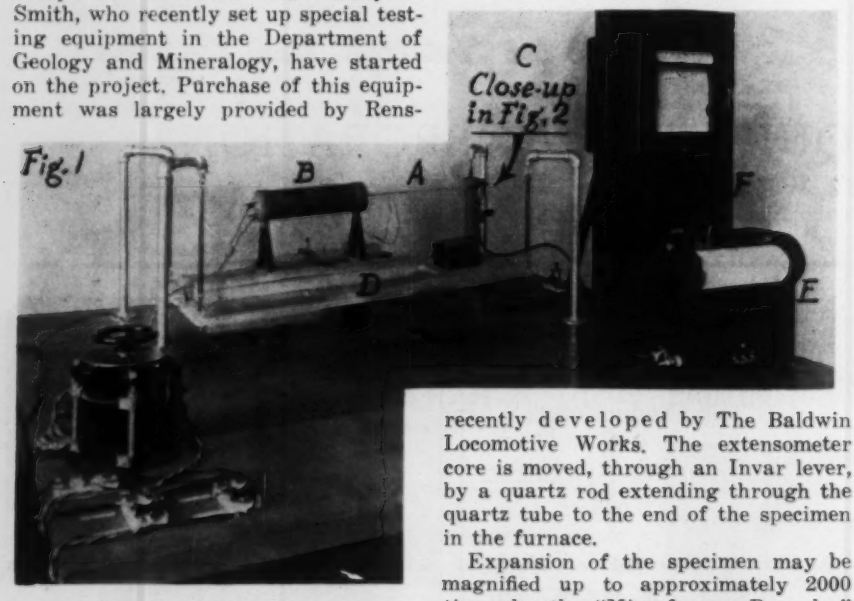
INSTRUMENTS ON THE MARCH

Autographic Instruments Measure Thermal Expansion of Earth Materials

TROY, N. Y.—Fundamental thermal expansion data of highest accuracy on many earth materials have become of enough importance to justify a thorough research project. Such data, needed by industries that use and manufacture ceramic materials, will be obtained over a period of several years at Rensselaer Polytechnic Institute. Professors Joseph L. Rosenholtz and Dudley T. Smith, who recently set up special testing equipment in the Department of Geology and Mineralogy, have started on the project. Purchase of this equipment was largely provided by Rens-



selaer's Research Fund but also by grants-in-aid from the Carnegie Corporation, New York, and the Research Corporation, New York.

The investigators will determine the linear thermal expansion of rocks and crystallographically oriented mineral specimens at temperatures ranging from 20 C. to 1400 C. (68 F. to 2550 F.) Mineral transformation temperatures will also be determined.

Specimens are quarter-inch square prisms half an inch long which are prepared by sawing mineral crystals parallel to their crystal axes. Diamond saws are used for most minerals. They are placed in the closed end of a 20-in. long quartz dilatometer tube (A in Fig. 1). This end of the tube is in a small cylindrical electric furnace (B) and the open end extends horizontally out of the furnace and into an Invar sleeve on a follower unit (C) that was specially designed by the Testing Equipment Department of The Baldwin Locomotive Works. Furnace, tube and extensometer unit are mounted on a spring-suspended platform (D).

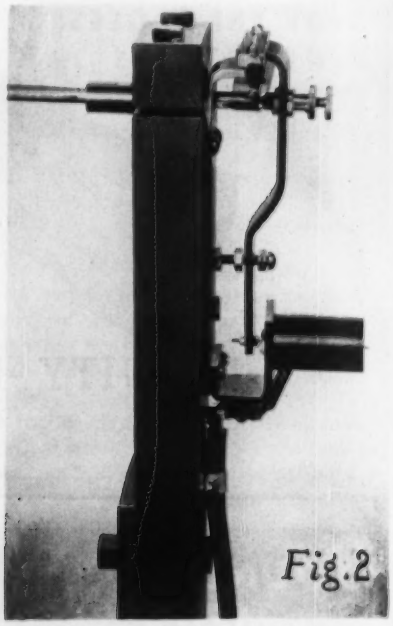
The microposcopic changes in length of the half-inch specimens with increasing temperature are measured by the Invar follower unit (C) which incorporates a "Microformer" extensometer recently developed by The Baldwin Locomotive Works. The extensometer core is moved, through an Invar lever, by a quartz rod extending through the quartz tube to the end of the specimen in the furnace.

Expansion of the specimen may be magnified up to approximately 2000 times by the "Microformer Recorder" (E) which automatically draws a deformation-time curve on the recorder chart. This equipment incorporates a self-balancing transformer bridge sensitive to length changes of the order of two millionths of an inch. Displacement of the core of the extensometer follower unit in either direction unbalances the bridge circuit. The unbalanced signal is amplified and drives a servomotor which, in turn, rotates the recorder drum and at the same time moves the recorder core to a position where its output again balances that of the extensometer.

Temperatures are controlled and recorded by a special Leeds & Northrup two-instrument "Micromax" unit (F) which makes it possible to heat and cool at predetermined rates and, of course, to hold any pre-set temperature. The recording instrument part of this equipment draws a time-temperature curve.

The investigators expect to improve the accuracy of thermal data on many materials as well as to determine the thermal properties of other materials for which no data are available. If several specimens of each material are tested to check results, the total time required for each material may be several weeks since some minerals must be studied in three directions, requiring at least nine determinations plus the time for cutting and for setting up.

Plans have been made to obtain data on all important minerals and rocks over a period of years. Although it is a full-time project only during the summer, the fact that the equipment is fully automatic in operation after being set up makes it practicable to obtain a large volume of data during the scholastic year. The investigators have previously published expansion data on quartz and several feldspars.

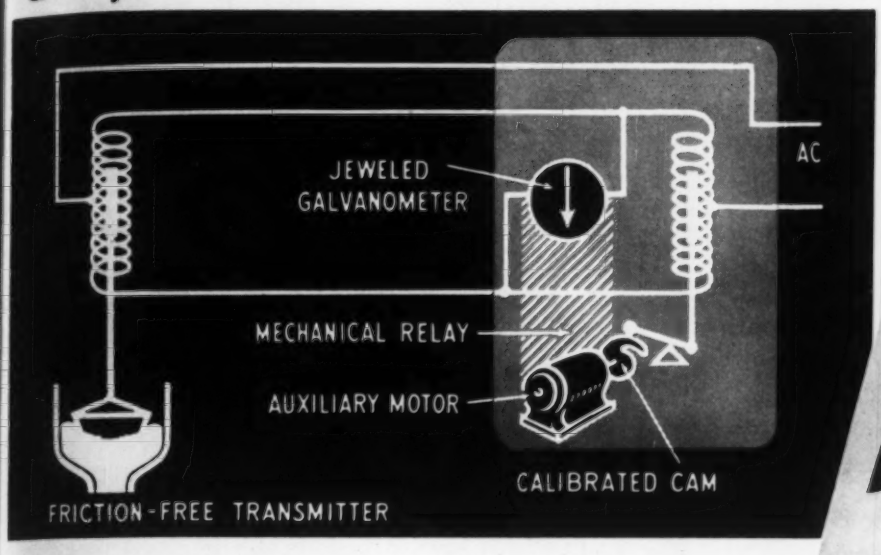


New Lightmeters for Use by Non-Experts

BOSTON, Mass.—A new technique for constructing light-sensitive cells so as to make possible for the first time the accurate measurement of illumination "in the field" was described here before the Illuminating Engineering Society. G. B. Buck II, illuminating engineer of General Electric's Lamp Department, with headquarters at Cleveland, O., displayed three new instruments for measuring light intensities, each employing cells made by the new method. He pointed out that the new construction almost completely corrects the errors, "often as great as two to one," existing in present light and exposure meters.

Mr. Buck stated that in the past no instruments existed which could assure that the specified lighting-installation

Why HAYS-COCHRANE FLOW METERS



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An extremely difficult metering job provides an ideal demonstration of the dependable accuracy and freedom from maintenance built into Hays-Cochrane Flow Meters.

Unlike most flow meters, the sensitive measuring circuit is relieved of all work of indicating, integrating and recording.

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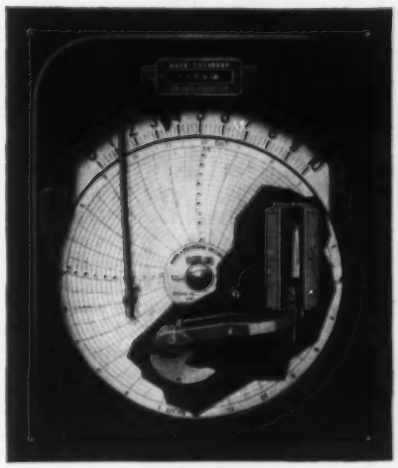

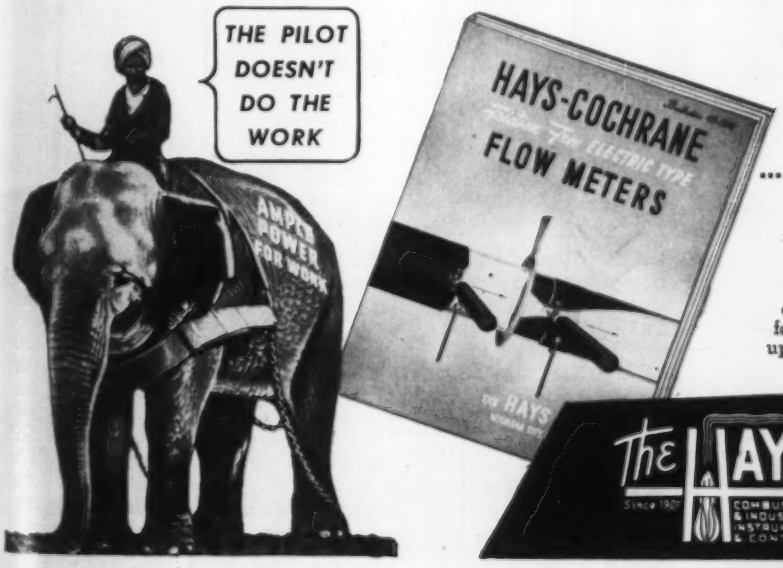

YOU'LL WANT THIS BOOK

For full information on these modern electrically operated flow meters—how they are made, how they work, how they keep their accuracy through long continuous service—send for Bulletin 49-800. It's a "must" for every up-to-the-minute data file.

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Do you depend upon badly scaled or decarburized work to tell you that something has happened to your furnace atmosphere? And then spoil more work getting the atmosphere back to where it belongs?

A Gordon Furnace Atmosphere Indicator will watch that for you. It makes a continuous, thorough check of the furnace atmosphere, and as soon as it changes, the change is detected and indicated so that quick necessary adjustment can be made. It works on gas or oil-fired furnaces and in protective atmospheres on electric furnaces.

The Gordon Furnace Atmosphere Indicator works on the principle of the relative thermal conductivity of gases. It is so simple and easy to use that top results can be obtained with shop or non-technical personnel.

Where a continuous record of atmosphere readings is required, the indicator can be co-ordinated with a recorder.

You can't afford to be without this instrument any longer.

Price, complete with U-tube and Sample Filter, 110 V, 60 C, **$335.00**

Write for descriptive bulletin for full information.

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footcandles were attained, light meters being so inaccurate as to require the interpretation of their readings by lighting experts.

The errors in present light and exposure meters were said by Buck to be of two types. One is caused by the color of light, the cells in light meters being more responsive than the human eye to blue and ultraviolet wave-lengths of energy. The other error results from the reflection of light, especially when the light strikes at an angle, from the surface of the cell and its protective glass cover plate. He described the technique for correcting the errors caused by color and reflection as consisting of the cementing of proper lenses and, in some cases, filters, to the cells themselves.

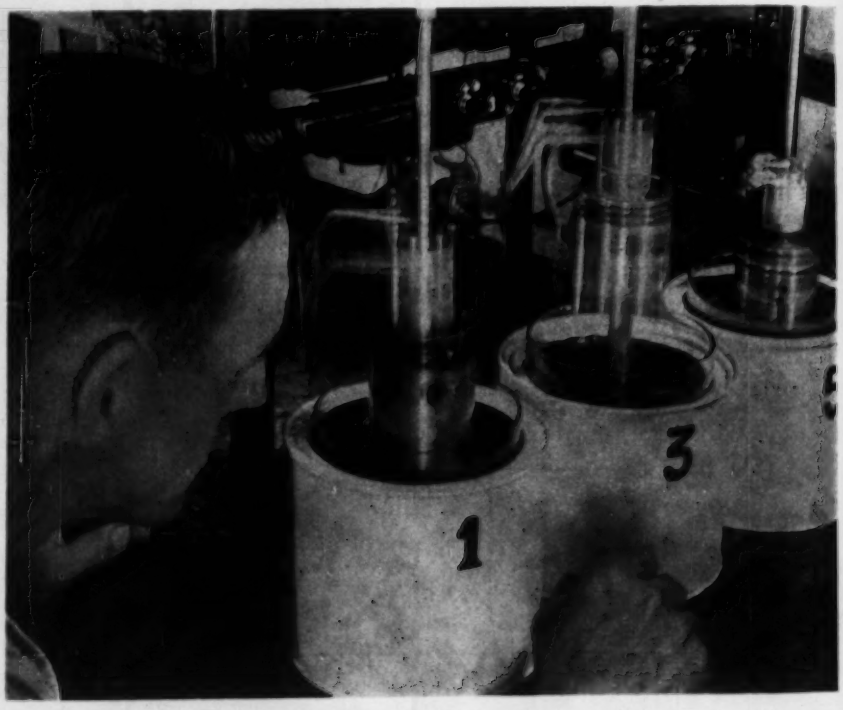
What is expected to be the most popular of the new instruments is a pocket-size light meter using e of the laminated cells. It was sh n by the speaker, who said that its a racy is within 10% for any color light or angle of light incidence.

A larger new instrument, the Low-range Precision Light Meter, was shown by Buck, who described it s being "almost perfect in its angu r response." One feature of the strument—the mounting of the cel in a gimbal, similar to those used in naval gyro compasses—eliminates the need for hand leveling, and greatly speeds engineering studies of street lighting, which often must be made under hazardous traffic conditions. Buck declared that this instrument is 100 times more seneitive than the pocket instrument.

The third instrument displayed by the G-E engineer was the "Multi-range Precision Light Meter," having ten

New Technique for Measuring Piston Temperatures

NEW YORK CITY. — A new and more efficient method of measuring heat within a piston moving as fast as 2000 rpm. within an engine was revealed today by engineers in the Beacon, N. Y., laboratories of The Texas Company. Exact knowledge of internal piston temperatures is vital to the testing and development of new types of lubricants, the engineers pointed out.



Older mechanical devices for determining piston temperatures fail under high speeds, heat, and reciprocating motion of the pistons, and formation of oil films results in open electrical circuits. The new technique employs air-cushioned plungers which contact at intervals a thermocouple placed inside the piston. Heat is determined by measuring, on a millivoltmeter, the thermocouple output, and thorough elimination of oil films is achieved.

In the new contact technique the thermocouple's terminals are mounted on a holder which extends below the piston skirt. Plunger tips to contact these terminals are installed in the crankcase. A pushbutton valve induces air pressure behind the plungers, forcing them out into contact with the terminals. Contact is made at the lower portion of the piston stroke. After readings are taken the valve returns to its normal position, inducing a vacuum behind the plungers.

The actual contact is wiping, which eliminates formation of oil films on the contact points. Contact is held long enough so that instruments used need not be extremely sensitive.

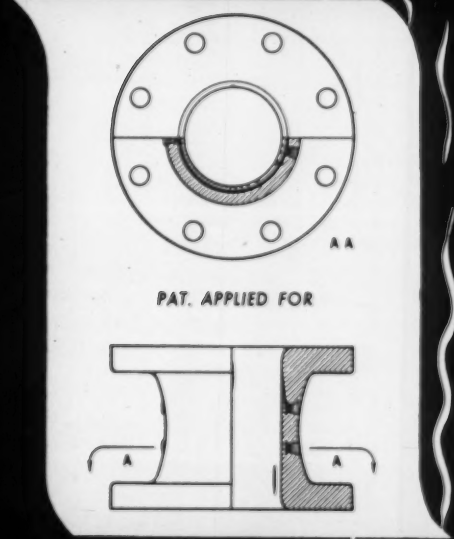
NEW BETHLEHEM FLOW TUBE

(Gentile Patents)

NO STRAIGHT RUN LIMITATIONS
NEGLIGIBLE RESISTANCE TO FLOW

A constant coefficient over 8:1 range of discharge, higher accuracy, more economy, greater range—these are some of the advantages of the new BETHLEHEM FLOW TUBE. Tested by one of the nation's leading hydraulic laboratories, it consists essentially of a short, straight length of pipe equipped with two groups of pressure nozzles around the inner periphery—one group pointing upstream, the other downstream. The nozzle groups are interconnected by common pressure rings from which connections are made to the high and low pressure sides, respectively, of a standard flow meter.

To measure fluid flow rate with greater accuracy . . . more economy . . . investigate this new primary element now! Write for your copy of the folder, "Bethlehem Flow Tube," today.



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For photographic recording of d.c. or a.c. currents with "flat" frequency response to as high as 2500 cycles per second. Available in a wide range of natural frequencies, all having high factors of sensitivity and dynamic balance. Their tubular hermetically sealed construction insures long-lived dependability and ruggedness. Magnetic assemblies are constructed for 2, 4, 8, 12 and 14 element mounting.

Century also offers a complete repair service on all types and makes of oscillograph galvanometers. Recent expansion of facilities makes possible immediate service.

Manufactured under Century Pat. 2439576, also licensed by Kannestine Laboratories Patent 2149442.

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World's Largest Manufacturer of Geophysical and Special Galvanometers

times the sensitivity of the pocket device. He said it incorporates both color and angular correction through the use of the laminated cells. Its major applications will be in the laboratory; and also in certain field studies where the ultimate in precision is required.

Ultrasensitive Lead-in-Air Spectroscope Detector

DETROIT, Mich. — The Optical Society of America learned about a new instrument capable of detecting lead in the air in amounts at least as low as one part in twenty million. Henry Aughey of the Chemical Department of E. I. du Pont de Nemours & Co., Wilmington, Del., who described the instrument, said it gives promise of adaptation for detecting in the air toxic metals encountered in certain manufacturing processes. The instrument's extreme sensitivity can be maintained in routine operations; and determinations of lead content can be made almost instantaneously, he said.

In the manufacture of various lead compounds, amounts of lead in the air must be kept at extremely low levels to avoid danger to workers, Mr. Aughey said.

One part in seven million, on a weight basis, is the maximum safe concentration allowable; and the instrument was developed, Mr. Aughey explained, as additional insurance of the highest possible degree of safety in tetraethyl manufacture.

The instrument is mobile; it may be wheeled to all parts of the plant for regular air inspections; it is far more sensitive, and faster, than all previously known orthodox chemical methods.

Air drawn from the area under investigation passes through an electrical spark discharge. The light from the spark discharge is passed through a quartz spectograph. If any lead in the air is drawn through the spark, it emits a narrow band in the ultraviolet spectrum. The band of light caused by the presence of lead in the air is passed into a photoelectric Geiger counter specially manufactured by the North American Philips Co. This gives rise to a pulsating current of electricity, the strength of which depends upon the intensity of light going into the photoelectric counter. The intensity of this light, in turn, depends upon the amount of lead in the air which was passed through the spark discharge.

Technical Societies

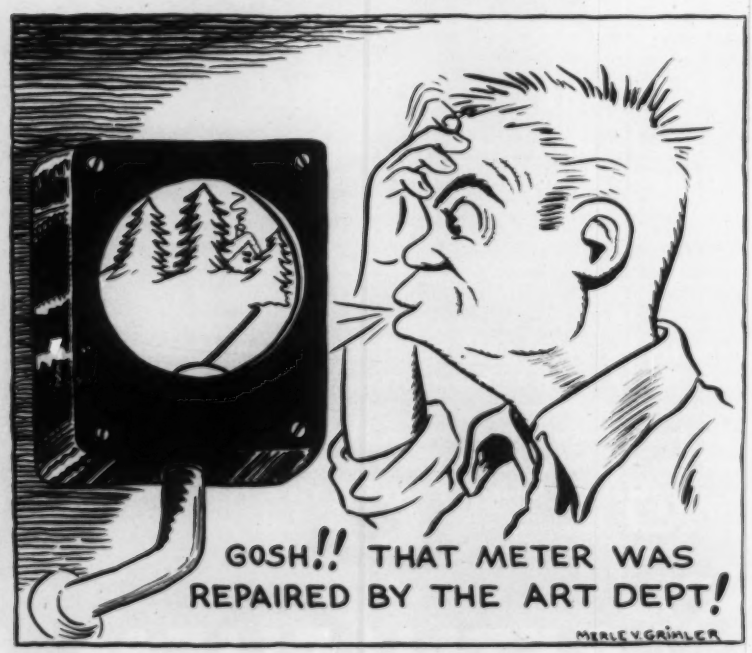
Philadelphia Sponsors ASC Continuation Course in Process Control

The Philadelphia Section of the American Chemical Society will again sponsor special non-credit courses designed to advance the training of chemists in the Philadelphia area. Classes will be located at the Philadelphia College of Pharmacy and Science, 43rd and Kingsessing Avenue, Philadelphia, open to both members and non-members of the ACS.

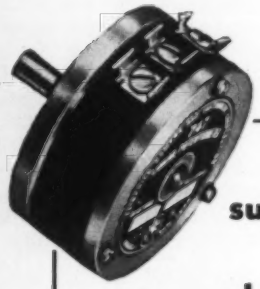
The course on Industrial Instrumentation Process Control is designed for chemical engineers and chemists who are concerned with the design and operation of chemical processes. Mr. Joseph Horn, a well-known authority in this field, will present the ten lectures on Monday evenings beginning February 21.

Information may be secured from Dr. J. F. Gall, Whitemarsh Research Laboratories, Pennsylvania Salt Mfg. Co., Wyndmoor, Pa.

Instru Merriment



Fairchild Precision Potentiometers



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For high power from a small unit, the new Burgess A. M. Power Units are *unexcelled!* Single cell units scarcely larger than an ordinary flashlight cell deliver currents as high as 100 amperes, at approximately 1.4 volts!

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A. M. Units are packed dry and activated with water . . . once activated they may be efficiently discharged at temperatures as low as −60°F. and as high as +150°F.! Write Dept. AM for full information on standard and special types.

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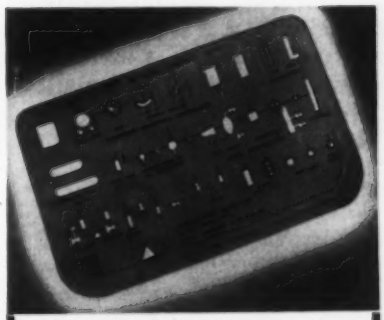

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No. 47 Price $3.50

Symbols used in layouts and schematic diagrams of recorders, indicators, controllers, manometers, etc., are QUICKLY and EASILY constructed with the Instrument Symbols Template!

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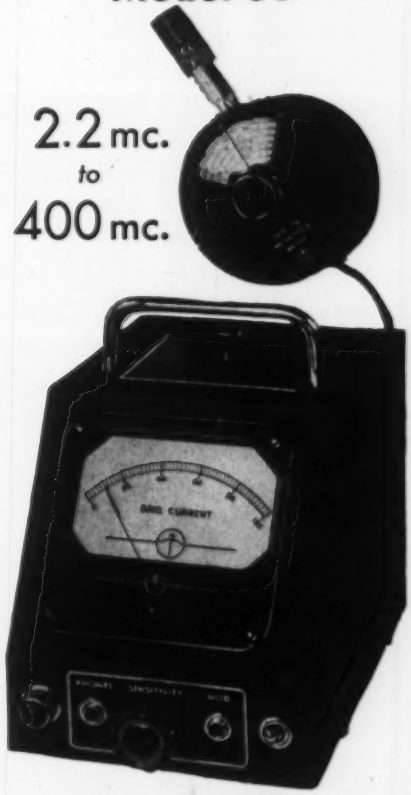
2.2 mc. to 400 mc.



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Radio's newest, multi-purpose instrument consisting of a grid-dip oscillator connected to its power supply by a flexible cord.

Check these applications:

- For determining the resonant frequency of tuned circuits, antennas, transmission lines, by-pass condensers, chokes, coils.
- For measuring capacitance, inductance, Q, mutual inductance.
- For preliminary tracking and alignment of receivers.
- As an auxiliary signal generator; modulated or unmodulated.
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Phase Sequence Indicators
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SPECIFICATIONS:

Power Unit: 5⅛" wide; 6⅛" high; 7½" deep. Oscillator Unit: 3¾" diameter; 2" deep.

FREQUENCY:
2.2 mc. to 400 mc.; seven plug-in coils.

MODULATION:
CW or 120 cycles; or external.

POWER SUPPLY:
110-120 volts, 50-60 cycles; 20 watts.

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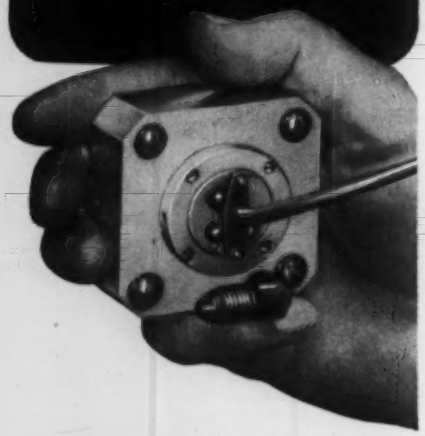
BOONTON NEW JERSEY

REMOTE INSTRUMENTATION
BY BENDIX-PACIFIC

Introducing the New

TTP-8A TELEMETERING PRESSURE GAGE



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ATOMIC CLOCK

Concluded from page 145

there are about 120,000 collisions per second, giving an experimentally-measured Q of 45,000 for the absorption line used. (This is the 3,3 line, for which the quantum numbers J and K are each equal to 3).

Actually, there are more collisions effectively interrupting the absorption process in ammonia than the kinetic theory of gases would indicate. Further broadening of the line results from collisions of the molecules with the walls, and even near-misses between molecules cause interaction strong enough to interrupt absorption. The number of collisions per second, and thus the collision broadening, can be reduced by lowering the gas pressure. This process, if not carried too far, does not reduce absorption in the gas, because the decrease in number of molecules absorbing energy is offset by the increase in absorption per molecule resulting from the increase in Q. However, when the pressure is reduced too much a phenomenon known as saturation of the line sets in, caused by an excess of radiation. Too few molecules are then left in the proper energy states to absorb the microwave radiation coming into the cell. Many molecules, which normally would be in the proper energy state to absorb the incoming radiation, are in an excited state as a result of previous absorption. Eventually these molecules will emit the quanta which they have absorbed, returning to the normal level where absorption is again possible. However, as this process is slow, the molecule usually returns to the ground level in a collision with another molecule, converting the absorbed radiation into heat. As the gas pressure is lowered, the number of collisions is greatly reduced, and not enough molecules return to ground level. The excessive incoming radiation then weakens and broadens the absorption line through saturation.

Saturation can be eliminated by reducing the strength of the incoming radiation. However, as the gas pressure and radiation intensity are both lowered, a condition will finally be met for which the signal strength will be down in the natural electrical level of the circuits used to detect the signal. Circuit noise then sets the ultimate limitation on the reduction of collision and saturation broadening. It is estimated that a Q of 300,000 to 400,000 can be attained at pressures of about one micron—still a long way from the Q of the natural line width. Assuming that effective Q values of 400,000 can be obtained with ammonia, an accuracy of one part in 100 million or better should be possible since a measurement of the center of the absorption line to within 0.004 of the width of the line could be made.

The author wishes to express his appreciation to B. F. Husten, E. D. Heberling, and other members of his staff for assistance in the design and construction of the atomic clock.

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Vol. 4 **FEBRUARY 1949** **No. 2**

General News

EDITORIAL

The December 1948 Aruba Bulletin carries a guest editorial by W. F. Hughes, the incoming president of the Aruba Section. I enjoyed this editorial and I believe that the officers and members of the ISA can profit by reading it. So, with thanks to Mr. Hughes; here it is — "We call ourselves a society, and yet I wonder if, in the selection of the word, and its association to our group, we fully understand the reason for our choice of the name. Webster defines it as "companionship or association with one's fellows", and by that very definition takes it out of the cold and stilted position so often atributed to some societies. This is justly so, for ours is one born of a common interest; one to group people together to further scientific development, to improve proper installation and maintenance, and to expand the interest of all in instrumentation.

"Some societies, organizations and club groups have been accused of a selfish motive in forming to-gether. We, of the Instrument Society of America, have been guilty of the offense and yet, to the best of my knowledge, have never been so accused. That may seem a rash statement, but our society has been formed of persons who felt that instrumentation and its wide application, can, and shall make a better and a more efficient industrial world. This will naturally result in a higher standard of living and a more pleasant world in which to live. What could be more selfish than to ask that of one's future? And if the ISA is formed of such people, who can blame their selfishness?

"Since our inception it has been our goal to further the appreciation, expand the application and improve the maintenance of instrumentation. We are now faced with two questions; have we done our best, and if not, what can we do to improve? If we say yes to the first, we are not only wrong but short sighted, for ours is a new field, full of chances to find a better way, one that finds wider application and a fuller appreciation of instrumentation, properly maintained.

"In our first years it was not easy, and although we are growing in numbers it is no easier today and we must appreciate the fact. We still have a tough job ahead of us but we still have the determination, and we trust the foresight, to continue to carry our objective. "We, the new officers and committeemen, appreciate the efforts of the men who have paved the way. We thank them for a precedent well set, and hope to carry on the good work."

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SECOND ORGANIZATIONAL MEETING OF INSPECTION AND GAGING SUB-SECTION PITTSBURGH SECTION ISA

The second meeting of the new Inspection and Gaging Group was held in the Hotel Henry, Pittsburgh, on Tuesday evening January 18th to take action on the organization of the group as a sub-section of the Pittsburgh Section ISA and to elect temporary officers.

The guest speaker of the evening was Dr. Ernest J. Abbott, President of the Physicists Research Company, who gave a most interesting and educational talk on "The Profilometer and its Application to Inspection." Dr. Abbott introduced the subject with a brief history of the measurement of surface irregularities, enumerating shop methods in pre-instrument days and pointing out the need and relative recency of numerical graduations or descriptions of surface roughness. The development of instruments for measuring surface profiles numerically was well illustrated with slides of the first Profilometer. Subsequent refinements of the instrument through the many adjustments to industry's needs were shown. The versatility of the Profilometer was pointed out by showing its adaptability to various surface roughness measuring problems in different industries. At the close of the discussion the members were invited to run their own tests and familiarize themselves wit hthe operation of the demonstration Profilometer provided by Dr. Abbott.

After the educational program the business of the meeting was taken up and the 29 members of the group present voted to join the ISA as a sub-section of the Pittsburgh Section. The following temporary officers were elected:

President: James R. Barbour, Chief Inspector Westinghouse Airbrake Co. Wilmerding, Pa.

Vice President: Arthur S. Marthens, U. S. Navy Inspection Service Rm. 405, Old Post Office Bldg. Pittsburgh 19, Pa.

Treasurer: George W. Linkhauer, Chief Inspector United Engineering & Foundry, First National Bank Building, Pittsburgh, Pa.

Secretary: Richard Rimbach, 1117 Wolfendale St. Pittsburgh 12, Pa.

Section Number 43 Is Chartered

We are happy to welcome Section No. 43, to be known as the Inyokern Section. This group has 96 members and the officers are:

H. A. Van Dyke, President, Pro tem.
A. S. Auchterlonie, Treasurer
P. O. Box 471
Inyokern, China Lake, Calif.

Membership Kit Is Mailed to Committee Members

Members of the Sections and Membership Committee now have a membership list to assist them in organizing sections and solving section problems. The kit contains:

1—ISA Constitution and By-Laws
2—Brochure on the Aims and Objectives of the ISA.
3—Typical Section By-Laws
4—Suggestions on Organizing a Local Section.
5—Committee Activity and Answers to Questions likely to be asked by local groups.
6—ISA Membership Application
7—List of ISA sections
8—Section Data Form
9—List of Speakers
10—Speakers Rating Form
11—List of Motion Pictures
12—Typical Section Meeting Announcement
13—Sample Section Magazine
14—Program and Exhibit Guide of the 1948 Conference and Exhibit
15—Copy of Instruments containing the ISA Journal.

Courses on Instrumentation and Automatic Control Proposed

By J. B. McMahon

Sometime ago Hugh Ferguson, our national treasurer and Chicago Section member, expressed to Captain Pettyjohn, Director of the Institute of Gas Technology, which is connected with Illinois Institute of Technology, his rather vigorous opinions concerning the deficiencies of the gas industry in applying Instrumentation and Automatic Control. Mr. Ferguson feels that a great deal could be done to correct this situation through instituting courses in Instrumentation and Automatic Control in our engineering colleges. Captain Pettyjohn took his remarks rather seriously and addressed a letter concerning this situation to President Heald of the Institute. President Heald turned the matter over to Dean Winston of the Institute Evening School, who thereupon got in touch with Mr. Ferguson and requested that a Committee of the Chicago Section of ISA meet with a Committee of the Institute faculty to discuss this matter. President Siechen of the Chicago Section appointed the Committee consisting of J. B. McMahon, Chairman; D. S. Dickey, and L. C. Laird. This Committee met with the Committee from the Institute and was supplemented by Mr. Ferguson and Mr. Siechen. The Committee from the Institute consisted of the following:

F. D. Carvin, Professor of Mechanical Engineering and Director of the Department
LeVan Griffis, Professor of Mechanics and Director, Instrumentation and Research in Mechanics
W. A. Lewis, Research Professor of Electrical Engineering and Dean of Graduate School
E. S. Pettyjohn, Director of Institute of Gas Technology
J. H. Rushton, Professor of Chemical Engineering and Director of the Department
B. S. Swanson, Instructor in Chemical Engineering
James S. Thompson, Professor of Physics and Chairman of the Department
S. E. Winston, Professor of Mechanical Engineering and Dean of the Evening Division

At a luncheon at the Institute, the question was discussed thoroughly and it was agreed that there was probably an opportunity for the Institute to create three different types of courses. The first would be on the vocational level and would consist of instruction for maintenance mechanics; the second would be at the undergraduate level and would be given to seniors in mechanical and chemical engineering, who had sufficient previous work in physics, chemistry, hydraulics, and mathematics to understand the technical phases of this field; the third would be a graduate course at a high mathematical level and would probably go deeply into the theory of automatic control of servomechanisms.

As a result of this joint meeting, the separate Committees from the Society and from the Institute are going to study the problem further and meet later to work out complete details. It is hoped that it will be possible to hold a summer course on maintenance and that both day school and evening courses may be started at the college level at the opening of the fall session next September.—From Chicago Section Events, January, 1949.

Section News

CENTRAL INDIANA

The January 11th meeting was held in Cropsy Auditorium in the Public Library. After the business meeting, Mr. K. R. Gieser of the General Electric Company gave a lecture on the fundamentals of Instrument Servo-Mechanisms and Instrument Telemetering. The February 8th meeting will be held in the Athenaeum. Refreshments will be served.

—E. E. Taylor, *Corr.*

CHICAGO

Official business of the December 6th meeting was opened by President R. R. Siechen. This constituted reports from C. C. Hurst, treasurer as to the financial condition of the section and O. M. Haseltine with the progress of the Membership committee. The guest speaker for the evening was Mr. Lee Wilcoxon, Director of Training of the Practical Electricity and Commercial Electronics Schools at the Industrial Training Institute of Chicago. His talk was entitled "Industrial Applications of Electronics."

Mr. Wilcoxon spoke in a non-technical manner designed to reach everyone. Clarifying the word "electronics" and differentiating between solid and gaseous conductors, he then spoke of the history of the vacuum tube from the "Edison Effect," through the "Fleming Valve," to radar, television and the unknown, unforeseeable future. The many amazing applications of electronic spot welders, from wash basins to submarines, and the use of electronic deep heating was interesting to hear.

Mr. Wilcoxon's discussion of photoelectric tubes, responsive over the full spectrum, and their use in instrumentation, and tube amplification of thermocouple output, was told so that even I could understand it. I also learned the difference between vacuum and gaseous tubes—each designed for its own specific purpose; that vacuum tubes are designed for amplifications by control of the grid voltage but are limited in power output; that gaseous tubes are designed to allow large current flows—but that they do not have the degree of control possible with vacuum tubes; and finally that a combination of the two can be ideal.

—Roy Johnson, *Corr.*

EASTERN NEW YORK

The January meeting of the section held on January 1, 1949 at Siena College was well attended by 43 people despite the floods and icy road conditions.

Preceding the regular meeting, slides and a recorded lecture on "Harnessing of the Electron" was presented and was very well received. It was voted to continue this procedure of showing educational films before the regular meeting each month.

After a few items of section business, the meeting was turned over to Bob Bushman, acting chairman of the program committee, who presented the speakers of the evening, Mr. Robert Gray, American Meter Company, Erie Works, who presented a paper on "Null Balance Telemetering by the Variable Frequency System" and Mr. W. V. Stockton, American Meter Company, Albany Plant, who presented a paper on "Volumetric Flow Meters." Both Mr. Gray and Mr. Stockton had brought working exhibits with them and members and guests showed much interest in inspecting the equipment and the speakers were quite busy answering the many questions that arose. The next regular meeting will be held on February 1, 1949 at Siena College. Mr. P. S. Dickey of the Bailey Meter Co., Cleveland, Ohio, will present "Recent Developments in Automatic Control for Power and Process Industries."

—W. J. Claffie, *Corr. Sec'y.*

INYOKERN

Reporting briefly on our Janu[illegible] meeting which was held on the 12th, [illegible] were favored with a talk by Mr. C. A. [illegible]z and Glifford White, both of Statham [illegible]abora-tories of Los Angeles, who inspire[illegible] great deal of interest. The subject was [illegible] Strain Gages and Associated Instrume[illegible]tation. Ninety-one members were in atte[illegible]nce.

Plans are underway to hold a jo[illegible] meeting with the California (Los Ange[illegible]) Section during the first week in Apri[illegible] on this Station, and we would like to e[illegible]nd an invitation to members of the ISA [illegible] large who may happen to be in the are[illegible] during that week to be our guests at t[illegible] same time. Plans for the joint meeting include an extended tour of the Naval Ordnance Test Station ranges with as compr[illegible]hensive a view of the activities on the Station as can be given within security regulations. The affair will consume most of the day, the guests arriving by special bus from Los Angeles early in the morning and returning late that evening in the same manner.

If the invitation is extended we would suggest that contact be made with the Los Angeles Section so that they can include the request for clearance on our Station along with the names of the members of their section who will join the party.

—H. A. Van Dyke, *Pres. Pro-Tem.*

NEW JERSEY

The January 4th meeting was held at the Essex House, Newark, New Jersey, and featured a talk by Mr. W. D. MacGeorge, Director of Research, Automatic Temperature Control Company, Philadelphia. His subject was, "Some Recently Developed Electronic Instruments."

Mr. MacGeorge described the construction and properties of a new type of differential transformer. Using working models of the equipment, he demonstrated the application of this device to transmission of pressure, flow and weight measurements. He also described and illustrated circuits with which the device could be used to add several measurements algebraically or in predetermined ratios. Following his talk, Mr. MacGeorge answered numerous questions regarding the equipment.

At this meeting, the members of the section were happy to welcome as new members William J. Angus, Jr., E. Robert Kebbon, George C. Whitehead, Jr., John E. Booth and Samuel A. Anderson.

Our members and friends will have the pleasure of hearing Mr. Ward Percy of United States Steel Corporation describe "Instrumentation Practices in the Steel Industry", at the section meeting to be held February 1st. Members of other sections who may be in the vicinity of New York are especially invited to join us in hearing this talk, and are also urged to attend our March 1st meeting when Mr. J. W. Grach, Imperial Oil Company, Ltd., will tell us about "Starting Up Process Units and What It Teaches the Instrument Engineer." Both of these meetings will be held at 8 P. M. at the Essex House, Newark, New Jersey.

—W. A. Hagerbaumer, *Corr.*

Continued on Page 182

See Article On Next Page

THE AUTHOR

Mr. Barnard graduated in Mechanical Engineering from New Hampshire in 1935 and became associated with Bailey Meter Company that same year. During World War II he was active in applying automatic control and electronic type instruments to merchant and naval vessels. His attention has recently been devoted to the development and application of electronic type gas analyzers for oxygen and combustibles. He is now engaged in the application of instruments and control systems for the improvement of process operation.

Clayton H. Barnard

The ABC's of Multi-Element Control

By CLAYTON H. BARNARD*

SINCE the development of continuous process operation the trend has been to higher through puts and higher product quality, both of which necessitate more precise control. The complexity of process has increased, and the application of automatic control equipment to most processes requires concentrated effort on the part of personnel experienced in control application.

Considerable investigation has been done to determine controllability of processes, nearly all of which has been based on single-element controllers since the majority of controllers in use today are of this type. The concepts thus gained must be abandoned when considering control of the multi-element type since processes which are considered uncontrollable with single-element controllers can usually be handled very successfully with multi-element systems.

Single-element controllers are operating on processes having some process lag, and the newer control functions and wider adjustments made available in controllers have been of material assistance. However, where proportional bands up to and exceeding 1000% are employed in order to secure stability, satisfactory control can be obtained only under the most ideal conditions and over a limited range of operation.

A single-element controller measures one variable and usually controls one function. A multi-element control system will measure several variables, and through proper coordination, control one or more functions. Multi-element control may thus be divided into two basic types:

1. A system in which several variables are measured and coordinated to control a single function
2. A system where several variables are measured and coordinated to control several functions

It should be noted that a multi-element system does not include control of the so-called "series" type, where several single element controllers are installed, each one measuring a single variable and in most cases controlling a single function. In a few instances, a single element controller may control two functions in parallel, and this type of operation should not be considered as multi-element control.

Some of the advantages of multi-element control may be stated as follows:

1. Multi-element control overcomes the effect of process and transfer lag
2. Multi-element control eliminates the effect of uncontrolled variables
3. Multi-element control eliminates inter-action between processes
4. Multi-element control provides inherent safety to processes which may become dangerous under poor control.

1. In any continuous process which is to be operated in equilibrium, the supply energy must at all times be equal to the demand energy, and the demand energy must be supplied at a suitable potential for the process. The potential may be expressed in terms of temperature, pressure, level, concentration, or many other terms. It is true that a measurement of potential is an approximate measurement of the ratio of energy supply to energy demand, and in many cases it becomes an accurate measurement. When this is true, single-element control will function successfully.

On processes having considerable process and transfer lag, the potential measurement no longer becomes an instantaneous measurement of supply and demand energy ratio, and poor quality control results.

By actually measuring both supply energy and demand energy, and introducing control functions based on these measurements, the effects of process and transportation lag are eliminated.

2. In many processes, variables other than the one being measured have nearly as great an influence on the process, and cause upsets which cannot be corrected fast enough or accurately enough for precise control. By measuring and controlling from each major variable, the extraneous effects are eliminated.

3. In some of the more complex processes, it may be possible to control demand potential with fair precision, even though the instantaneous ratio of energy supply to demand does not remain constant. While this may be satisfactory for the particular portion of the process under consideration, the inter-action on other sections of the process make it undesirable in every case, and in many cases, intolerable. By obtaining complete stability of the process through proper coordination of all major variables, these effects are eliminated.

4. Where processes have considerable lag, and where deviations in the ratio of supply to demand energy may become dangerous, a multi-element system will correct for the deviations before any serious conditions arise.

To see how these advantages work out in actual application, it is well to consider a few typical applications of multi-element control systems to processes common to many industries.

The contact type heater illustrated by Fig. 1 is required to furnish water at an uncontrolled rate to the next section of the process. In the particular example shown, steam is supplied for heating through a constant pressure valve at a rate to maintain a constant pressure, and thereby a constant temperature within the heater. The storage capacity of the heater is comparably small because of economic reasons, and it is necessary to supply water so that heated water at a constant temperature and pressure will at all times be available as required for the process. A single element type level controller would control the rate of water flow to the heater in accordance with level, which would likely be unstable in view of the small storage capacity and uneven dis-

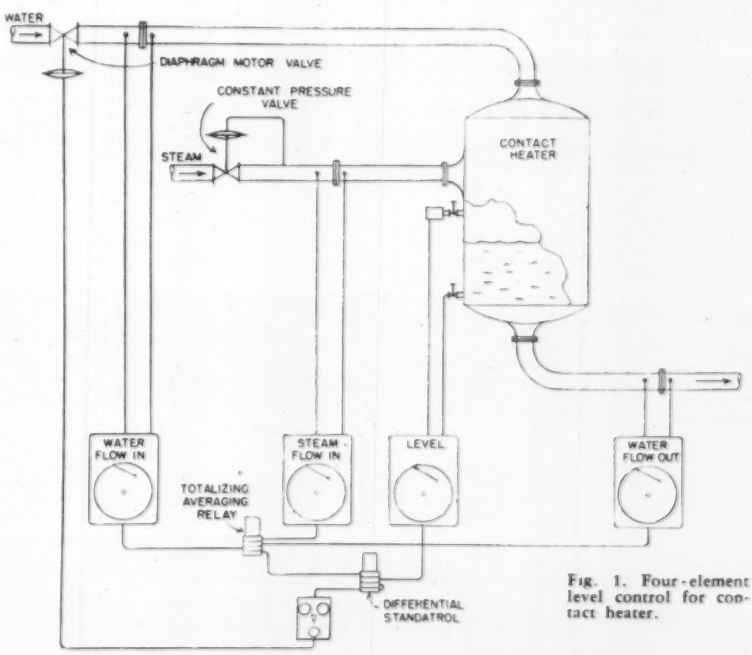

FIG. 1. Four-element level control for contact heater.

*Presented at the third annual conference of the Instrument Society of America, Sept. 13-17, Philadelphia, Pa.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of the author and not those of the Society.

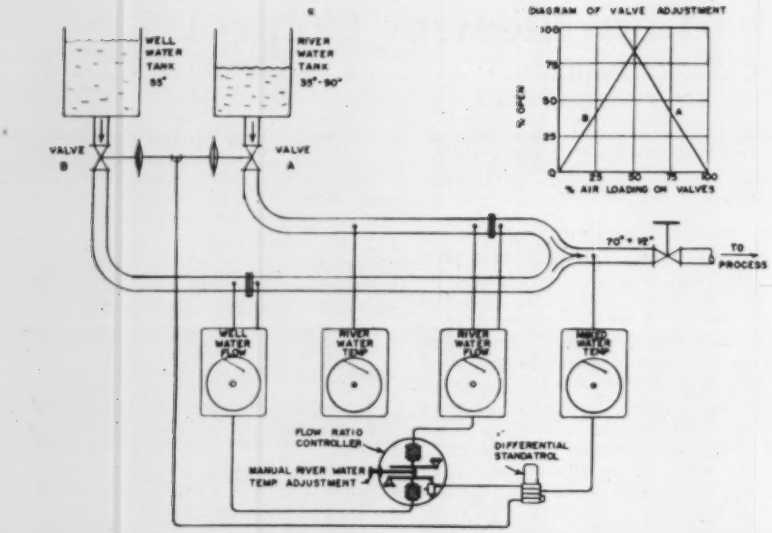

Fig. 2. Three-element temperature limiting control.

tribution of water storage. This instability would vary the rate of water flow to the heater considerably, which could very well have an effect on the preceding process from which the water is drawn. Similarly, the rate of water flow would change the steam demand in direct proportion, and cause abnormal changes in demand on equipment supplying the steam.

In order to obtain the utmost stability of the process and satisfy the requirements of wide range operation, a 4-element control system as illustrated can be used to advantage.

Since the main purpose of the heater is to provide water as required, it is desirable to make the primary controller a measurement of the energy demand, in this case the water flow from the heater. Water flow to the heater, as well as steam flow to the heater are also measured individually, and added algebraically in the totalizing averaging relay. This relay actually becomes a ratio controller, in which the total water flow to the heater, and steam flow to the heater which condenses to water, is balanced against water requirements as measured by the flow controller on the outlet line. The primary control is to balance the ratio of any energy supply to energy demand, which is the first requirement for stable operation in any continous process. An impulse from the level controller is introduced to the differential standatrol to modify the ratio sufficiently to maintain a substantially constant level within the heater at all times, providing the maintenance of the necessary energy potential.

It should be noted in this application that the pressure of the water entering the valve supplying water to the heater has no effect on the maintenance of proper temperature and level, since the flow is actually measured and the valve positioned to maintain this flow at the required amount, irrespective of the pressure. Temperature of the water entering has only a minor influence on the system, its only effect being the introduction of a slight error in the water flow measurement, which can readily be taken care of by a small automatic readjustment by the level instrument. Process lag and transfer lag are completely overcome due to the supply and demand energy ratio being maintained in equilibrium at all times.

Interaction between processes is eliminated by the maintenance of complete stability in this entire system, through the measurement of all the important variables.

The system shown should be considered typical only, and will require modification for individual problems of this type.

Fig. 2 illustrates the application of multi-element control to a water mixing problem requiring high accuracy and wide range operation. Water is supplied to the process from two tanks, the well water tank being at a relatively constant temperature, and the river water tank being at a temperature varying with the season of the year. It is essential that a minimum of well water be used because of relative scarcity, and it is essential that the water to process, to be supplied at an uncontrolled rate, never exceed a fixed maximum temperature. The problem is further complicated by the fact that the level of the water in the two tanks is controlled by on-off motor pumps, so that the level in the two tanks may be anywhere within wide limits. The primary control is to measure river water flow and well water flow individually, and control the ratio of the two depending on the river water temperature. Since the changes in river water temperature are seasonal, manual adjustment of the ratio is satisfactory. An impulse from final mixed water temperature is introduced to the differential standatrol, and combined with the output of the flow ratio controller to regulate valves A and B.

The adjustment of the two valves is illustrated, and it should be noted that one valve is wide open, or nearly so, under all conditions so as to prevent abnormal head loss in the system. Because of the large transfer lags involved, the wide range of operation required, and the variable heads of water from the two tanks it would be impossible for a single element controller to operate satisfactorily, unless a number of additional devices were installed.

The application of the system shown will provide complete compensation for the variable heads involved, the wide operating range, and the river water temperature. It is interesting to note that when the river water temperature is only slightly above the maximum permitted to the process, a very small pro-

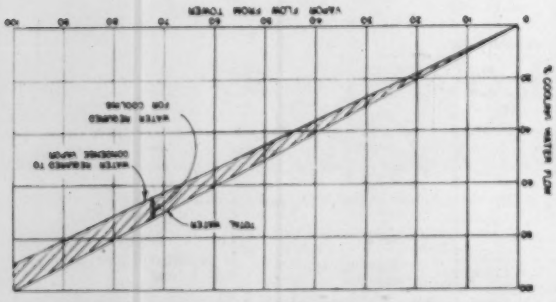

Fig. 3. Cooling water requirements for a condenser cooler.

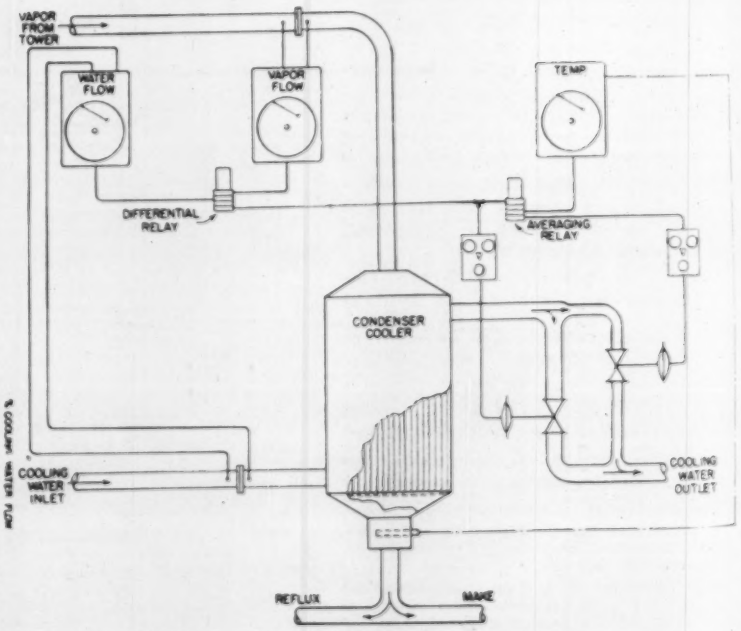

Fig. 4. Multi-element temperature control for a condenser-cooler.

portion of well water is required, whereas a large proportion of well water is required when the river water temperature reaches its maximum.

In many processes, a condenser receiving vapor from a tower is also used as a sub-cooler in order to deliver condensate to the succeeding process at a constant potential. Fig. 3 illustrates the water requirements for such a system, and it will be noted that the bulk of the water is required for condensing the vapor and only a relatively small portion of the total water is required for sub-cooling. A single element temperature controller regulating a water valve in the cooling water line would be called upon to do an almost impossible job, since the sensitivity of the valve would be very high insofar as temperature control is concerned, as it has to be oversized in order to provide sufficient water for condensing.

Fig. 4 illustrates a multi-element control system for such a condenser-cooler which will overcome the obstacles preventing satisfactory use of a single element controller.

It is assumed that vapor will be delivered from the tower at a constant temperature, and under these conditions the water required for condensing is in direct proportion to the amount of vapor. Impulses from the measurement of vapor flow and water flow are combined in the differential relay to regulate the two water valves installed in parallel. One valve is comparatively large in size, in order to provide approximately the correct amount of water for the condenser, and this valve is controlled directly from the ratio of vapor flow to water flow without any readjustment. The impulse from the ratio control system is combined in the averaging relay with an impulse from the temperature controller to regulate the smaller water valve which is sized to provide sufficient water for sub-cooling and regulating purposes only.

The operation of this system is such that changes in vapor flow rates from the tower immediately move both valves in approximately the correct amounts, and it is only necessary for the temperature controller to trim the small valve to maintain precise temperature control.

As in the preceding application, the effect of process lag and transfer lag are overcome, and the interaction on the preceeding and succeeding processes is eliminated. Cooling water pressure has no effect on the system and complete stability of the entire process is obtained.

The three examples stated have generally been of the type where several variables are measured, and one function controlled. A more complete multi-element control system for refinery heaters is illustrated by Fig. 5, and this involves several measurements and the control of several functions.

The heater illustrated is of vertical type having two parallel coils which must be controlled individually in order to compensate for coking and unequal distribution of the combustion gases which would have an effect on the balance of the heater. It is also necessary to maintain the temperature in the transfer line at a predetermined amount, and maintain the rate of charge to the heater constant. It is also required to operate the heater at maximum efficiency and with complete safety, which requires the maintenance of the proper fuel-air ratio.

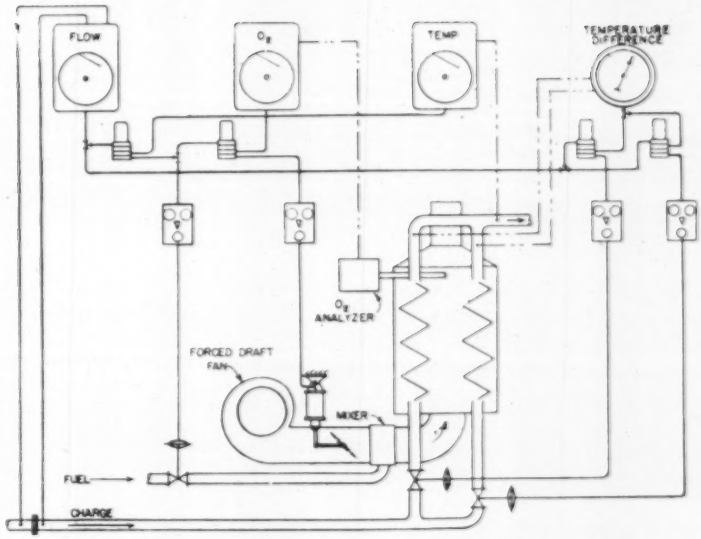

Fig. 5. Coordinated multi-element control for a refinery heater.

The basic control is by an impulse from a measurement of charge flow, which regulates the two valves in the individual lines to the two coils, and also provides the primary impulse for controlling the fuel and forced draft air. A temperature difference indicator is used as an index of balance of the two coils and an impulse introduced through the two averaging relays as indicated to modify the setting of the flow control valves in such a manner that flow through the two coils is unbalanced as necessary to maintain equal temperatures leaving the heater. It should be noted that this modification does not in any way effect the total flow, as one valve is opened and the other closed.

Temperature of the oil in the transfer line establishes an impulse which is combined with the impulse from the charge flow controller through an averaging relay to supply fuel at the proper rate and also to modify the forced draft air supply.

An oxygen analyzer taking samples at the exit of the heater is used as an indication of fuel-air ratio, since it provides compensation for variations in fuel supply, so very prevalent in refinery practice. The oxygen recorder-controller impulse is combined with impulses from the charge flow controller and transfer line temperature controller to maintain the forced draft supply at exactly the proper amount for maximum combustion efficiency.

This system provides complete stability of the entire heater operation, and also prevents interaction between preceding and succeeding processes. As in the other cases, it overcomes the effect of process and transfer lag, and provides for optimum safety.

It should be noted in this instance that the control equipment required is actually simpler than a series system consisting of a multitude of single element controllers each acting independently, and which will not provide the stability, lag compensation, and safety which are inherent with the system illustrated. It is questionable if this complete process could be controlled by single element controllers with as little equipment as is required for the multi-element system.

An analysis of the illustrations points the way to a few simple rules which can be used as a guide in applying systems of this type:—

1. Measure each important variable in the process and from each measurement introduce a control impulse in such a way that it will influence the functions to be controlled in approximately the correct amounts.

2. Arrange the equipment in such a way that the final measurement of energy potential has only to be a modifying controller.

3. When in doubt, use an impulse from the doubtful factor, since it can always be eliminated if it is found unnecessary, and the cost of providing for it in the original installation will be far less than applying it later if it is found necessary.

Multi-element control is not new and untried, but a proven result of many years' development. Originally designed for use on boilers where there are now in service many thousand systems for controlling feedwater, combustion, steam temperature and other factors, processes where the highest quality it has already been adapted to many control is required.

In the future, it is going to be necessary to depend more and more on multi-element control systems in order to obtain the precise control, operating safety and high throughputs which will be required with a minimum of major equipment.

The increasing use of end-product analyzers almost invariably makes multi-element control necessary in view of the relatively large transfer and instrument lags involved, and the best application of such equipment is to use it as a modifying controller rather than as a primary controller.

As the trend toward more complete automatic operation progresses, all sections of a plant will be coordinated with a common control system so that all separate processes within a given area will be correlated. These advancements cannot be expected in the immediate future but the trend is definitely in that direction, and only multi-element control can provide the necessary coordination for satisfactory results and maximum return on investments.

SECTION SECRETARIES AND MEETING DATA

	Telephone	*Date*	*Dinner*	*Meet*
Akron: Fred Appel, 932 Columbia Ct., Barberton, Ohio.				
Aruba: M. R. Holly, P. O. Box 389, c/o Lago Oil & Transport Co., Ltd., Aruba, N.W.I.		1 Tues.	X	7:0
Atlanta: Emory W. Clark, P. O. 819, Atlanta, Ga.				
Baltimore: Felix Cox, Bethlehem Steel Co., Sparrows Point, Md.		2 Fri.		
Boston: C. J. Nazzaro, 456 Central Avenue, Milton 87, Mass.		Last Wed.	6:00	7:00
California: D. D. Taylor, 234 E. Colorado, Pasadena 1, Calif.		1 Tues.	6:45	
Central Illinois: T. A. Carroll, 721 Hurlburt St., Peoria, Ill.		1 Wed.	6:30	7:30
Central Indiana: M. Underwood, 1235 W. 33rd St., Indianapolis, Ind.		1 Tues.	X	7:30
Charleston: Albert H. Hix, 1529 B Dixie St., Charleston 1, W. Va.		1 Mon.	X	8:00
Chicago: Floyd E. Erstman, 506 S. Wabash Avenue, Rm. 611, Chicago 5, Ill.		1 Mon.	6:30	8:00
Cincinnati: Smith Hickenlooper, 1147 Beverly Hills Dr., Cincinnati, Ohio.		4 Mon.		
Cleveland: L. H. Waldrip, 3030 Euclid Ave., Cleveland, Ohio.		4 Wed.	6:30	8:00
Cumberland: Clyde Babst, P. O. Box 447, Cumberland, Md.		*Tues. after 4 Mon.*	6:30	8:00
Detroit: T. S. Cawthorne, 570 Maccabees Bldg., Detroit 2, Mich.		3 Tues.		
Eastern New York: Wm. J. Claffie, Winthrop-Stearns, Inc., 33 Riverside Ave., Rensselaer, N. Y.		1 Tues.	6:30	8:00
Gulf Coast: A. E. Bunn, 2237 North Street, Beaumont, Texas.		3 Tues.		
Houston: E. E. Kleir, 2510 S. Blvd., Houston 6, Texas.		Last Mon.	X	8:00
Inyokern, China Lake, Calif: H. A. Van Dyke, (Pres. Pro Tem), P. O. Box 277, Inyokern, China Lake, Calif.				
Kansas City: Lewell F. Spies, J. F. Pritchard & Co., 908 Grand Ave., Kansas City, Mo.		Last Tues.	6:30	7:30
Louisville: H. C. Scherffius, 980 Palatka Rd., Louisville, Ky.		4 Tues.	X	8:00
Montreal: F. S. McCarthy, Canadian Industries, Ltd., Box 10, Montreal, Quebec, Canada.				
New Jersey: W. D. Archibald, 605 Westminster Ave., Elizabeth 3, N. J.		1 Tues.	6:00	
New Orleans: W. H. Haney, 2927 Music Avenue, New Orleans, La.		*No Regular Date*		8:00
New York: C. E. Haggerty, 7552 181st St., Flushing, L. I., N. Y.		Last Mon.	6:30	8:00
Niagara Frontier: K. J. Fees, 669 Ashland Avenue, Niagara Falls, N. Y.		4 Mon.	X	8:00
Northern Indiana: C. P. Haynes, 935 177th Place, Hammond, Indiana.		3 Wed.	6:30	7:30
Oak Ridge: John H. Clark, 138 Clayton Hall, Oakridge, Tenn.		1 Wed.	7:00	
Ontario: A. J. Legault, Bristol Co. of Canada, Ltd., Toronto, Ontario, Canada.		3 Thur.	6:45	
Philadelphia: C. W. Wood, 6908 Market St., Upper Darby, Pa.		3 Wed.	X	8:00
Pittsburgh: L. M. Susany, c/o Carnegie Institute, 4400 Forbes St., Pittsburgh 13, Pa.		4 Mon.	6:30	8:00
Presque Isle: R. P. Marshall, 161 W. Main St., North East, Penna.		4 Tues.	X	8:00
Richland: R. S. Hammond, 402 Abbott, Richland, Washington.		2 Wed.	X	7:30
Rochester: R. C. Swartz, Jr., 1201 Granite Bldg., Rochester 4, New York.		3 Tues.	X	8:00
St. Louis: W. G. Lee, 4710 Delor St., St. Louis 16, Mo.		1 Wed.	X	8:00
Sarnia: C. G. Elder, 323 Maria St., Sarnia, Ont., Canada.		2nd & 4th Fri.	X	
South Bend: Charles E. Williams, 921 Lawndale Avenue, South Bend, Ind.		1 Thur.	6:30	7:30
South Michigan: Homer Kuiper, 2517 Hillsdale, Kalamazoo, Mich.		2 Wed.	6:30	8:00
South Texas: H. C. Givens, La Gloria Corp., P. O. 637 Falfurrias, Texas.		1 Tues.	X	7:30
Tennessee: L. W. Thayer, 1229 Bristol Highway, Kingsport, Tenn.		*No Definite Night*	7:00	8:00
Tulsa: C. R. Horton, 8211 E. 7th, Tulsa, Oklahoma.		1 Mon.	X	7:30
Twin Cities: Ray Hooper, International Div. Minneapolis-Honeywell Reg. Co., 2753 Fourth Ave., Minneapolis 8, Minn.		4 Tues.	6:30	
Washington: Edwin G. Brown, c/o American Instrument Co., 8010-20 Georgia Avenue, Silver Spring, Md.		3 Mon.	X	7:30
Wayne County: R. L. Swenson, 1569 13th St., Wyandotte, Michigan.		3 Mon.	6:30	8:00

Continued from Page 178

NIAGARA FRONTIER

The Niagara Frontier Section held its Christmas Party on December 20, at John Lindner's Restaurant in Buffalo. No formal business meeting was held. About forty members were present and enjoyed an excellent roast beef dinner. The meeting afforded an excellent opportunity for members to improve acquaintanceship with each other. The party was adjourned at about 11:30 P. M.

W. J. SOMMERS, *Corr.*

OAK RIDGE

The following are the newly elected, officers of the Oak Ridge Section: President W. J. Ladniak; Vice President, K. E. Burmaster; Secretary, John H. Clark; Treasurer, George H. Griton; National Delegate, Warren H. Brand; Executive Counselor, Jack Mahoney; all from the local units of The Carbide and Carbon Cremicals Corporation. The new committee chairmen are: Publicity, Miss Martha R. Smith; Membership, H. B. Shnider; Nominating, S. A. Hluchan; Education, G. R. Jamieson; Program, J. H. Campbell. Among those who served in office during the past year are: B. B. Bell, Joe Alexander, A. K. Johnson, D. G. Davis and "Tiny" Isenhour. We feel that our organization grew more vigorous and healthier under their direction.

The first meeting of the year was held January 5th. We had a good attendance at the Dinner which preceded the regular business meeting. Mr. Nelson Gildersleeve, meter and Instruments Div., General Electric Co., was our first guest speaker. Mr. Gildersleeve first spoke about the I. S. A. This part of his speech was, mainly, concerned with ways and means of strengthening the member sections and the national organization. He said that the national office invited criticism from its members providing that the criticism is of a constructive nature. A prevailing attitude of this sort would bring about changes which would enable each member to get a greater return from his investment in the I. S. A.

Mr. Gildersleeve then discussed "Specialized Measuring Equipment Directly Pertaining to Process and Quality Control." He mentioned the importance of keeping the processed material exactly controlled at all times. This means that enough instruments of the analytical type must be used so that the operator will always know if the components of his process are correct and in the proper proportions. If so, the derivative will be of the desired quality and much waste eliminated. A number of slides were used by the speaker to show, more clearly, the application of these specialized instruments.

Our second guest speaker was Mr. George F. Gardner, Div. Engineer, of the General Instruments Div., Gen. Electric Co., Schenectady, N. Y. Mr. Gardner discussed the Halogen Leak Detector. He explained the construction of the instrument, its usage and problems encountered where it is used. He also discussed other instruments which he had been designing.

ROCHESTER

The December meeting was held December 14, 1948, at 8:00 P.M. in the Bausch and Lomb Physics Building on the River Campus of the University of Rochester. Dr. E. D. Haller of the National Technical Laboratories, Pasadena, Calif., spoke on the subject, "pH Measurement and Control." Dr. Haller spoke briefly about the fundamentals of pH measurement and equipment involved. The talk was based on a large number of slides which showed the various types of measuring devices and several applications of measuring and controlling pH in industrial processing.

A simple circuit involving the pH electrodes, a transmitter and a recording receiver with connecting cable and wires was discussed. This circuit was developed with the addition of several pH electrodes, various transmitting arrangements and multipoint continuous strip-chart recorders. Some of the problems involved in shielding, contamination and corrosion of electrodes were discussed.

The talk was concluded with the description of pH measurement and control on citrus fruit processing, ore processing, chemical manufacture, waste water processing, sewage disposal operations and several others. At the regular business meeting the nominating committee presented the following list of names as their selection for the coming year:

Irving G. McChesney, Chairman, Rochester Gas & Electric Corp.

Norman Loenig, Vice Chairman, Eastman Kodak Co.

Ralph Schwartz, Jr., Secretary, Foxboro Co. Representative.

Charles W. Covey, Treasurer, Taylor Instrument Companies.

Additional nominations will be in order from the floor at the January 25th meeting, at which time the election will be conducted. The speaker of this meeting will be Mr. John S. Leslie of Leslie Company, Lyndhurst, New Jersey.

—CHARLES W. COVEY, *Corr.*

SAINT LOUIS

The St. Louis Section had as its scheduled speaker for its January 5th meeting, Mr. C. R. Maise, Associate Director, Police Laboratory, St. Louis, Mo. His subject was, "Scientific Aspects of Crime Detection."

The Section also announces its program for the balance of the 1948-49 year:

February 2—Mr. Strickland, Proportioneers, Inc., "Proportioning Devices."

March 2—P. T. Ramey, Communications Supervisor, Union Electric Co., "Telemetering Electric Load."

April 6—J. T. McFarland, Hagan Corp., "Ring-Balance Flowmeters."

May 4—R. W. Boetinger, Leslie Valve Co., "Pressure Regulation."

—HENRY E. ZEFFREN, *Corr.*

SOUTH TEXAS

At the January meeting of the South Texas Section, the history and development of the modern calculating machine was outlined by Mr. B. B. McMullen, service supervisor of the Marchant Calculating Machine Company. The talk traced the mechanical development of the selection systems used in various types of calculators. As a climax the 'Figuremaster', Marchant's postwar achievement, which was released at the New York business show, was presented to the group. A discussion of color engineering, as well as mechanical features, closed the talk.

Mr. McMullen's talk was well received, though some were puzzled at the absence of pointer, stylus or derivative controller; or any correction for ambient air temperature. Such precision is strange to those of us down here who breathe natural gas as others do oxygen.

The results of our annual election were announced as follows:

Cecil M. Carson, President.
Jens P. Nielsen, first Vice-President.
T. H. Pierson, second Vice-President.
Homer C. Givens, Secretary and Treas.
L. Needham, Corresponding Secretary.

The Program Committee, consisting of Mr. Givens, Mr. Pierson, and Mr. F. A. Salmon, announced that Mr. Ed. Dahl, of the Hammel-Dahl Co., will address our next meeting on February 1st, and Mr. C. B. Moore, of Moore Products will speak in March. A dance is planned for March 18th.

—L. NEEDHAM, *Corr. Sec'y.*

WAYNE

Our regular meeting was held January 17th at the Episcopal Church Hall. After the customary visiting and other preliminaries we had an excellent steak dinner. We had some new applicants for membership. There was a brief business meeting.

Mr. Ted Clark, of Clark Bros. Instrument Company, was able to secure the Navy sound film "The Silent Service," which told of the part played by our submarines in winning the war. It was shown by Chief Petty Officer Chiviac and Petty Officer Bober. The days of Tokyo Rose, and the memory of our losses and success were brought back, and we have a new appreciation of the great service rendered by our submarines.

Our next meeting will be sponsored by the Metrol Company. Mr. Bruce Irwin of Hammel-Dahl will speak on "How to Select a Control Valve."

—JOHN MACPHERSON, *Corr.*

WYANDOTTE

Our Christmas Party was held December 20 at St. Stephen's Episcopal Church Hall. About eighty members and guests were present. The church ladies outdid themselves in providing dinner and Christmas decorations. We gratefully acknowledge the many donations of entertainment, door prizes, candy and cigars, etc., by members and manufacturers' representatives. Miss Rennick, of the Wyandotte High School, brought a group of young singers and musicians and their contribution was much appreciated.

The January 17th meeting will be held at the same place and the program will consist mainly of a movie showing instrumentation on a submarine.

—JOHN MACPHERSON, *Corr.*

Tentative Program—Toronto Spring Meeting

Lyman H. Allen, Jr., Chairman of the Program Committee for the Toronto Spring meeting at the Royal York Hotel, May 12 and 13, has received the following program tentative for this meeting from F. S. McCarthy who made the arrangements.

MAY 12:

Chairman Morning Session: President of the Toronto Section.

Speakers: W. J. Graeb—Subject to be announced: C. W. Hills—Subject to be announced.

Chairman Afternoon Session—R. J. S. Pigott (Pittsburgh Section).

Speakers: (To be announced). What Management Expects of an Instrument Department. Panel Discussion—Instrument Organization in the Process Industries. (Panel to be announced later.)

MAY 13:

Chairman Morning Session—President of the Sarnia Section.

Speakers: E. T. W. Bailey—Subject to be announced. G. A. Rice and E. W. Leaver. A Novel Liquid Chlorine Depth Gage.

Chairman Afternoon Session—To be announced. (To be announced). The Sulphite Process from the Point of View of the Instrument Engineer. Panel Discussion. Progress in Pulp and Paper Instrumentation.

The ISA Spring Meeting will be held May 12 and 13, at the Royal York Hotel, Toronto, Canada. Final program data will be available shortly.

Hotel reservations should be made with Mr. G. R. Street, Convention Manager of the Royal York Hotel:

One person to a room	$ 6.00	per day
Two persons to a room (Twin Beds)	$ 4.75	" "
Three persons to a room	$ 4.25	" "
Four persons to a room	$ 4.00	" "
Suites (Two persons)	$19.00	" "

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CHIEF ENGINEER for reorganized division of large manufacturer. Division operates in precision instrument field and heavy experience in the administration of an engineering organization devoted to development and design of precision instruments is required. Excellent opportunity for qualified man in age group of 40 to 50 years. Approximate salary $9,000 per year. Location Northern New Jersey. Box 217.

. . .

SALESMAN for laboratory apparatus and equipment to hospitals. Should have good technical knowledge of the constructional features and practical experience in the use of this equipment. College graduate with some experience in optics, physics, electrical engineering or electronics preferred. Headquarters Chicago. Box 218.

. . .

INSTRUMENT MECHANICS. Responsible positions are open in the new field of nucleonics at Hanford Works, Richland, Washington. Hanford Works is operated by G. E. for the U. S. Atomic Energy Commission. Positions require the maintenance, repair and calibration of a variety of complex industrial and electronic instruments. Those accepted will also assist on special instrument and control system work. Experience must include a minimum of three years' work as an instrument mechanic, at least two years of which has been in the field of industrial instruments and control system work. Those selected will become part of the permanent operating personnel at Hanford Works plutonium manufacturing plant located in southeastern Washington state. Write for Application. Box 219.

. . .

INSTRUMENT MECHANIC. Experienced man wanted to maintain and install electric and air operated instruments. Should have had at least 5 years industrial experience. Work in Pittsburgh Area. Box 220.

REMEMBER

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ROYAL YORK HOTEL
TORONTO, CANADA
MAY 12 and 13

ANNUAL MEETING
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Responsible positions are open in the new field of nucleonics at Hanford Works, Richland, Washington. Hanford Works is operated by G. E. for the U. S. Atomic Energy Commission.

Positions require the maintenance, repair and calibration of a variety of complex industrial and electronic instruments. Those accepted will also assist on special instrument and control system work.

Experience must include a minimum of three years work as an instrument mechanic, at least two years of which has been in the field of industrial instruments and control system work.

Those selected will become part of the permanent operating personnel at Hanford Works plutonium manufacturing plant located in southeastern Washington state.

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Employment Supervisor

Department "E"
GENERAL ELECTRIC CO.
Richland, Washington

Manufacturers' New Literature

In this department we report new literature pertaining to Instrumentation, received from the manufacturers. We urge readers to request ONLY those bulletins which will be of value to them. Use the Postage-free Order Card on Page 187.

R-57 ELECTRICALLY-OPERATED VALVES. 10-page bulletin gives information on, and describes maker's electrically-operated valves for various installations and uses. Included is a valve coil chart.—Atkomatic Valve Co., Inc., 1255 Roosevelt Ave., Indianapolis 7, Ind.

R-58 TEMPERATURE INDICATING PYROMETERS. 12-page bulletin illustrates and describes maker's automatic kiln controls and temperature indicating pyrometers designed to provide safe automatic control and remote indication for kiln and furnace users. — Assembly Products Inc., Main at Bell St., Chagrin Falls, Ohio.

R-59 LIQUID LEVEL CONTROL SWITCH. 4-page bulletin pictures and describes maker's liquid level control switch for indicating and controlling liquid levels. Operation, advantages, etc. are discussed. Instrument may be used to operate pump motors, valves, or indicating lamps.—Clapp Instrument Co., Webster, Mass.

R-60 THERMOCOUPLES. 8-page bulletin contains list of maker's line of standardized industrial thermocouples, their parts, assemblies, and accessories. Included in bulletin are thermocouples, thermocouple wires, lead wires, protection tubes, insulators, terminal heads and connectors. Arkley S. Richards Co., Inc., 72 Winchester St., Newton Highlands 61, Mass.

R-61 PROFILOMETER MEASUREMENT. 2-page bulletin describes and illustrates maker's "Type GB" tracer for taking surface roughness measurements on internal grooves and recesses. Maker states, tracer can be used with any type Profilometer amplimeter. Specifications are given —Physicists Research Co., Ann Arbor, Mich.

R-62 FIXED COMPOSITION RESISTORS. 4-page bulletin illustrates and describes maker's new "Type BT" which is said to be far in advance of present resistor performance. Outstanding characteristics are said to be particularly evident in high ambient temperatures. International Resistance Co., 401 N. Broad St., Philadelphia 8, Pa.

R-63 "THE CAPACITOR." 16-page Vol. 13 No. 9 issue of this house organ features article on television AGC and picture-tube voltage and signal systems. Also contains list of advertisements for buyers, sellers, and swappers.—Cornell-Dubilier Electric Corp., Hamilton Blvd., South Plainfield, N. J.

R-64 TIME ESCAPEMENT MOVEMENT. 4-page pocket size folder describes and illustrates maker's small, prescision built, time escapement movements for universal adaption to almost any associated time control mechanism. Diagram outlines dimensions and mounting arrangements. —Grayson Controls Div., Robertshaw-Fulton Controls Co., 3000 Imperial Highway, Lynwood, Calif.

R-65 MICROMETERS. 8-page bulletin pictures and gives information on "Type W" micrometer for continuous production measurement. Designed for factory use where high speed and laboratory accuracy are required. "Type W1" measures outside diameter of wire, thread, tubing, rod, edge to edge dimension of extruded parts, etc. Principal characteristics: no contact with object, no speed limit of wire or strip, object may vibrate up to 4 in., etc. Bulletin gives uses, description, specifications, etc.—Raymond M. Wilmotte Inc., 1469 Church St., N. W. Washington, D. C.

R-66 Z-ANGLE METER. 2-page bulletin describes and illustrates maker's z-angle meter for impedance and phase angle measurements. Bulletin gives range, applications, etc. Included is description of maker's precision variable resistors.—Technology Instrument Corp., 1058 Main St., Waltham 54, Mass.

R-67 ELECTRIC CIRCUIT CONTROLLER. 4-page Bulletin 502 describes and illustrates maker's electric circuit controllers of direct acting finger type, which maker states unites advantages of other types of regulators in one basic design which is small and light in weight. Can be used to control voltage, current, speed of motors, generators, etc.—Electric Regulator Corp., 1938 Park Ave., New York 35, N. Y.

R-68 AC-DC INSULATION TESTERS. 2-page bulletin illustrates and describes "model 2402" insulation tester designed for research, development, production or repair where various voltages up to 2000 volts are required in measuring break-down voltages; testing insulation of insulating materials, etc. Also describes and pictures "model 2415" D-C insulation tester for heavy duty research, repair, production, etc., where variable voltage up to 15000 volts is required.—Cole Instrument Co., 1320 So. Grand Ave., Los Angeles 15, Calif.

R-69 "CEC RECORDINGS." 4-page Vol 2 No. 4 issue of this house organ discusses adding plug-in damping resistors to oscillographs, introduces Clifford E. Berry, research physicist, etc. Contains article titled "Precision Workmanship Essential in producing Ionization Chambers." —Consolidated Engineering Corp., 620 N. Lake Ave., Pasadena 4, Calif.

R-70 PHASE MISCROSCOPES. 24-page booklet gives historical background of phase microscopy which permits study of living organisms and other transparent materials of inherently low contrast. Explains theory, describes and illustrates various models, and lists recommended phase objectives for specific applications.—American Optical Co., Scientific Instrument Div., Buffalo 15, New York.

R-71 THERMOSTATS AND PILOT-FAILURE SAFEGUARDS. 6-page bulletin describes "Unitrol" universal controls for water heaters, space heaters, etc. Each control contains thermostat and safeguards. —Grayson Controls Div., Robertshaw-Fulton Control Co., 3000 Imperial Highway, Lynwood, Calif.

R-72 "MODERN PRESCISION" Vol. 3 No. 3 8-page issure of this house organ features articles on new steam homo method for scale free tempering; accurately heat treating big forgings in "Micromax" controlled furnaces. Also contains articles titled: "Temperature Measurement and Control of Electrically Heated Molding Processes For Rubber and Plastics.", "Lube Tower Yields Up To 3 Percent More Naphtha With Speedomax Pneumatic Control at Coil Outlet."—Leeds & Northrup Co., 4902 Stenton Ave., Phila. 44, Pa.

R-73 "INSTRUMENTS NOTES" 8-page No. 6 issue of this house organ contains article titled "Calibration and Test Of Accelerometers," Illustrations are included.—Statham Laboratories, 9328 Santa Monica Blv'd, Beverly Hills, Calif.

R-74 "THE GENERAL RADIO EXPERIMENTER." 8-page Vol. 23, No. 7 issue of this house organ features articles titled: "A Low-frequency Multiplier For The Vacuum-tube Voltmeter". The Interpolating Frequency Standard Miscellany section included.—General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.

R-75. RECORDING THERMOMETERS. 8-page bulletin describes and illustrates maker's mercury actuated, vapor actuated, gas actuated recording thermometers. Contains information on selection of proper recording thermometer, lists maker's line of recording thermometer charts.—H. O. Trerice Co., 1420 W. La Fayette Blvd., Detroit 16, Mich.

R-76 ELECTRONIC VARIABLE SPEED CONTROL. 8-page Bulletin No. WTM-45 describes and illustrates makers electronic variable speed control for DC motors from AC power. Listed are advantages, standard speed ranges and torque characteristics, ordering information and specifications. Theory of operation is explained and schematic and block diagrams are used throughout. —Weltronic Co., Grand River at Pierson, Detroit, Mich.

R-77 PRECISION VARIABLE RESISTORS. 16-page bulletin illustrates and describes maker's "Type RV2" precision variable resistors. Mechanical and electrical specifications are listed along with prices.—Technology Instruments Corp., 1058 Main St., Waltham, Mass.

R-78 "MICRO TIPS" 4-page Vol. 1, No. 3 issue of this house organ contains ideas which were suggested for uses of maker's snap-action switches.—Micro Switch, Div. of First Industrial Corp., Freeport, Ill.

R-79 ELECTRONIC REGULATOR AND RECTIFIER. 4-page Bulletin No. WTM-50 describes

and Kieley & Mueller Engineers Responded with Designs as Modern as They are Practical!

This KONTROL MOTOR Pressure Regulator develops the high sensitivity needed for closer regulation. Extra-long, heat-treated springs, having low stress factors are used together with specially designed diaphragms molded to provide extra contact area. This combination assures uniform operating power throughout the stroke of the valves.

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These design advances are typical of the fresh, unfettered thinking Kieley & Mueller urged its engineers to employ in redesigning the entire line of automatic controls to keep pace with the demands of process industries for improved regulator performance under increasingly severe conditions.

Contents — Kieley & Mueller Catalog 47

Kontrol Motor Diaphragm Valves — Saunders Patent Diaphragm Valves Direct and Reverse Acting Diaphragm Motor Top Works — Accessories — 28 pages.

Pilot or Direct Operated Liquid Level Controls — Float Valves — Balanced Lever Valves — Ball Float Drainers — 30 pages.

Strainers — 4 pages.

Pressure Reducing Valves — Auxiliary Pilot Regulators — Pump Governors — 36 pages.

Steam Equipment — Back Pressure Valves — Atmospheric or Diaphragm Relief Valves — Stop Check Valves — Exhaust Heads — Grease Extractors — 16 pages.

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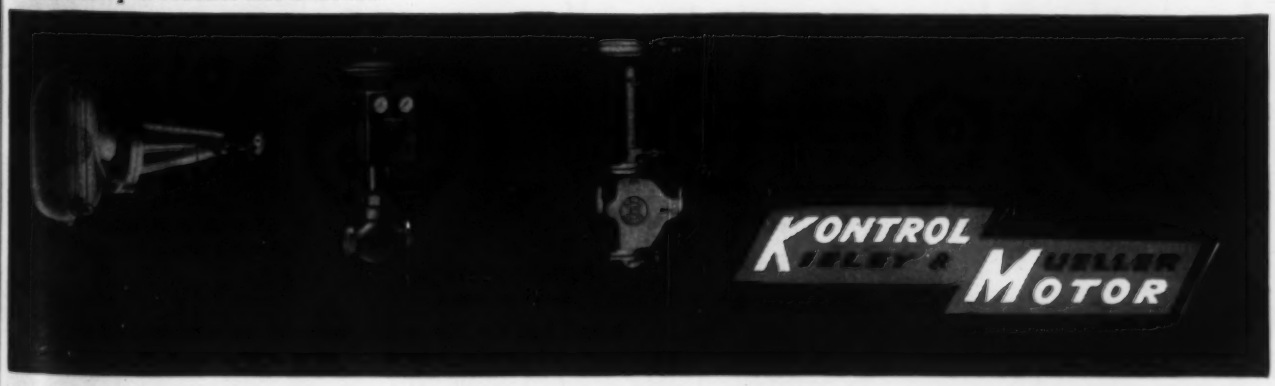

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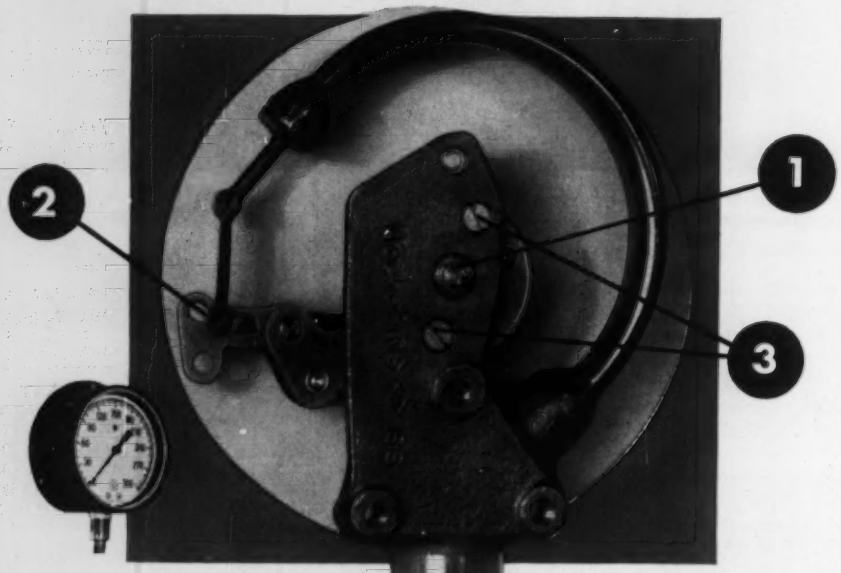

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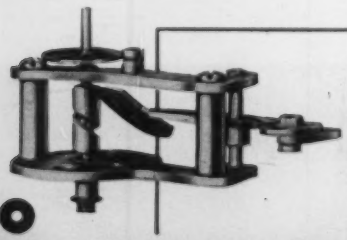

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and illustrates maker's field rectifier and power factor regulator, giving general description, standard types available. Theory of operation is explained.—Weltronic Co., Grand River at Pierson, Detroit, Mich.

R-80 VIBRATION RECORDERS. 4-page bulletin describes and pictures Cox "Type 4" vibration recorder, a portable instrument for recording torsional and linear displacement. Specifications, equipment, and auxilliary equipment are listed. Linear spring action translators, torsion translators, linear inertia translators, and linear contact translators are also pictured and described. —Commercial Research Labs., Inc., 20 Bartlett Ave., Detroit, Mich.

R-81 ELECTRIC POWER EQUIPMENT INSTRUMENTS. 38-page catalog ND4-33-461 is directed to men in public utility systems and in industrial power plants. Covers variety of instruments; portable and automatic indicators. Micromax and Speedex recorders for providing continuous temperature data; also instruments for measuring in rapid succession, a number of bearing temperatures. Thermocouples, thermohms, leadwires, charts, and other accessories are listed. —Leeds & Northrup Co., 4934 Stenton Ave., Phila., Penna.

R-82 MEGOHMER INSULATION AND RESISTANCE TESTERS. 4-page Bulletin No. 1248 shows in condensed form, all megohmer and insulation testers sold by maker. These consist of DC generator (hand-crank type) and non-cranking, battery-vibrator type. Herman H. Sticht Co., Inc., 27 Park Place, New York, N.Y.

R-83 PANEL METERS. 12-page Catalog No. 25 describes and illustrates maker's various models and sizes of panel meters. Panel mounting types, and external shunts for panel mounting instruments are listed.—Hickok Electrical Instrument Co., Cleveland, Ohio.

R-84 RECORDING PAPERS. 26-page bulletin answers all questions concerning maker's recording papers. Some of the many questions answered are: What is Alfax paper? What is meant by electro-sensitive? How actual marking takes place, etc.—Alfax Paper and Engineering Co., 40 Riverside Ave., Brockton, Mass.

R-85 ONE INCH METERS. 6-page bulletin gives description of, and illustrates maker's "Model 101" and "Model 103" meters for use where space is limited. Internal and external construction, ranges, and prices are discussed. Also described are: "Model 351" DC meter, "Model 1352" AC meter, both three and three fourths in.; "Model 701" DC meter, "Model 702" AC seven in. meters.—Assembly Products Inc., Main at Bell St., Chagrin Falls, Ohio.

R-86 FREQUENCY METERS. 2-page bulletin describes and illustrates maker's frequency meters in switchboard and aircraft type cases. Construction, size, and prices are discussed—Hickock Electrical Instrument Co., 10514 Dupont Ave., Cleveland 8, Ohio.

R-87 DAMPER CONTROL. 4-page bulletin pictures and describes maker's "Model DCR-A" time delay damper control. Application, instructions on installation, and specifications are discussed.—Cleveland Fuel Equipment Co., 1836 Euclid Ave., Cleveland, Ohio.

R-88 RESISTANCE TESTERS. 24-page Bulletin No. 21-20 illustrates and describes maker's "Megger" insulation testers of the heavy duty type. All improvements and accessory features are discussed. Hand-driven, motor-driven, and multivoltage instruments, their features, ranges, and applications are detailed for selection of proper instruments for specific insulation resistance measuring problems.—James G. Biddle Co., 1316 Arch St., Phila. 7, Penna.

R-89 CARBON DETERMINATORS. 4-page bulletin pictures and explains maker's carbon determinator No. 4500 DBBL, an instrument for rapid accurate determination of carbon in cracking catalyist. General description of operating procedure is discussed.—Laboratory Equipment Corp., St. Joseph, Mich.

R-90 INTEGRATING SPHERE DENSITOMETER. 6-page folder illustrates and describes maker's "RA-1100 Type" densitometer for determining proper exposure and processing techniques with both Pos. and Neg. sound-on-film recordings. Also for other types of photographic work. Specifications of densitometer are included.—Electrical Research Products Div. Western Electric Co., 233 Broadway, New York, N.Y.

R-91 POSITIVE SHUT-OFF VALVES. 12-page engineering report No. 94 provides performance data on over twelve hundred positive shut-off valves in service over five years on corrosive and penetrating fluids. Included are applications of hydrofluoric acids, propane, organic florides, etc. at various temperatures and pressures. Tabular data on valves in service with operating temperatures and pressures included.—Sellers Injector Corp., 1611 Hamilton St., Phila. 30, Penna.

R-92 "BAUSCH & LOMB MAGAZINE" Vol. 25, No. 1 issue of this house organ presents articles titled: "Optical Correctness," "Eyewear Performance," "Eye Care Unlimited" etc. Section titled "What's New In Scientific Instruments" also included.—Bausch & Lomb Co., Rochester 2, N.Y.

R-93 OVEN PYROMETERS. 4-page pocket size booklet illustrates and describes maker's "Model 165-A" simplytrol oven pyrometer for checking

temperature of all appliances. Procedure for checking various appliances is discussed.—Assembly Products Inc., Main at Bell St., Chagrin Falls, Ohio.

R-94 "TAYLOR TECHNOLOGY" Vol. 1, No. 3 issue of this house organ features articles about: one of the world's largest textile mills, fluid flow measurement in pipe sizes less than two inches, engineered instrumentation for canning retorts, and other articles.—Taylor Instrument Companies, Rochester 1, N.Y.

R-95 SPECTROMETERS. 6-page bulletin describes and illustrates three types of maker's spectrometers: "Research Model," to serve where precision is essential; "Standard Model," which permits performance of all standard experiments, and "Students Model," designed primarily for educational use. Specifications are given.—Helger & Watts Ltd., 48 Addington Square, London, England.—U. S. Agents, Jerrell-Ash Co., 165 Newbury St., Boston, Mass.

R-96 RADIOACTIVITY DETECTION AND MEASUREMENT. 4-page Bulletin No. 1048 pictures and describes maker's Geiger-Muller laboratory and field instruments for detection and measurement of radioactivity. Instruments described are: counting rate meters, laboratory counters, counter tubes, scalers, survey instruments, classroom demonstrators, etc. Features listed include: economy, simplicity, up-to-the-minute circuit designs, reliability, etc.—Boder Scientific Co., 719-21 Liberty Ave., Pittsburgh 22, Pa.

R-97 ELECTRIC POTENTIOMETER PYROMETERS. 16-page Bulletin No. 232-A illustrates and describes maker's "Pyrotron" potentiometer pyrometer. Listed are general specifications standard charts, performance data, etc. Diagrams are used throughout.—Bailey Meter Co., 1050 Ivanhoe Road, Cleveland 10, Ohio.

R-98 STEAM TRAPS. 6-page pocket size folder pictures and discusses maker's "No. 60" steam traps, one-half in. size, cast simi-steel construction, for pressures up to 150 psi; "Series 70" inverted bucket, from one-half in. to one in. size, cast simi-steel construction, for pressures up to 200 psi.; "Series 70-T" combination inverted bucket and blast type, cast simi-steel construction, for pressures up to 150 psi.—Clark Mfg. Co., 1830 East 38th St., Cleveland 14, Ohio.

R-99 ACCELEROMETERS. 14-page booklet discusses two new aircraft instruments: "G Warning" indicator, which flashes warning signal when aircraft approaches design load limit, and "G-Max" indicator which provides permanent record of g-loads encountered during any period of aircraft operation. Design features and importance of instruments are discussed.—Flight Research Engineering Corp., P. O. Box 1-F, Richmond, Va.

R-100 ELECTRO-MECHANICAL COUNTER. 2-page bulletin describes and illustrates maker's "ERA-1200" electro-mechanical counter that can be stacked to six digits, provide reliable carryover at operating speeds of 1200 counts per minute. Construction and features are listed. Model can be modified to meet specific requirements.—Engineering Research Associates, Inc., 1902 West Minnehaha St., St. Paul 4, Minnesota.

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R-101 HYDROSTATIC IMPULSE GAGES. 2-page Bulletin No. 121 describes and illustrates maker's "Model 44" hydrostatic impulse gages for data on following applications: underground explosions, underwater explosions, combustion chambers, geophysical tests, water hammer research, blasting operations. Specifications data sheet included.—Engineering Research Associates, Inc., 1902 West Minnehaha St., St. Paul, Minnesota.

R-102 "YARWAY NEWS." 8-page Vol. 4, No. 1 issue of this house organ is devoted to the history of Yarnall-Waring Co., and its products.

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